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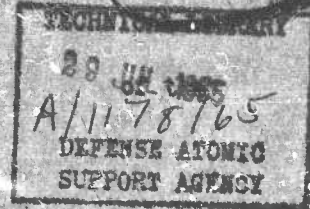
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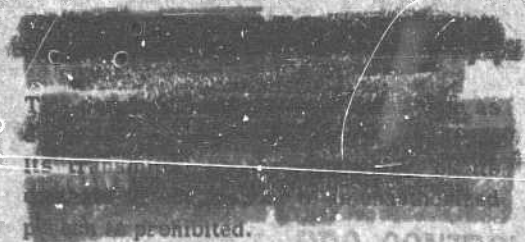
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SHOCK WINDS, AFTER-WINDS, AND CHANGES IN AIR
TEMPERATURE RESULTING FROM LARGE ATOMIC
BURSTS NEAR THE EARTH'S SURFACE



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Report to the Scientific Director

② SHOCK WINDS, AFTER-WINDS,
AND CHANGES IN AIR TEMPERATURE
RESULTING FROM LARGE ATOMIC BURSTS
NEAR THE EARTH'S SURFACE

① By
Maynard Cowan, Jr.

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ABSTRACT

Project 6.3 of Operation Ivy was designed to obtain experimental measurements of some of the characteristic parameters (dynamic pressure, temperature, velocity of sound) of blast waves from nuclear explosions to the complete histories of such blast waves. Measured peak dynamic pressures (q), temperatures, and sonic velocities are compared with those predicted from the Rankine-Hugoniot relations on the basis of measured overpressures and ambient conditions. Within the range of experimental error there is reasonable agreement between these measured peak changes in dynamic pressure (peak particle or wind velocity and density) and temperature across the shock front and those calculated.

Measurements of dynamic pressure and total head throughout the positive and negative phases were quite successful except at overpressure levels greater than 20 psi. Durations of positive and negative phase winds are found to be in agreement with the durations of the corresponding overpressures.

It was also desirable to obtain some measure of the velocities and durations of after-winds (post-negative-phase winds) if these proved to be at all significant from the point of view of damage. Velocities of after-winds resulting from both Mike and King shots proved too small to be measurable by the instrumentation used; on Mike shot they apparently had maximum velocities of less than 24 mph at 21,412 ft from ground zero.

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ACKNOWLEDGMENTS

Measurements of shock winds, after-winds, and temperatures on Mike and King shots of Operation Ivy were planned by representatives of the Los Alamos Scientific Laboratory and the Weapons Effects Department (5110) of Sandia Corporation. The author wishes to express his appreciation for the fine cooperation among the participating agencies and the personnel and contractors of the Pacific Proving Grounds.

Installation of the measuring instruments and recording of the field measurements were ably executed by personnel of the Pacific Proving Ground Division (5233) of the Field Test Organization of the Corporation. A list of all participating personnel is presented as Appendix A to this report.

The author is also grateful for the expert assistance of Miss Sally Langenstein in preparing this manuscript for publication.

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SHOCK WINDS, AFTER-WINDS, AND CHANGES IN AIR TEMPERATURE RESULTING FROM LARGE ATOMIC BURSTS NEAR THE EARTH'S SURFACE

1 PURPOSE AND SCOPE

Peak overpressure* has come to be more or less generally accepted as the primary criterion from which to predict the damage potentialities of blast waves from nuclear explosions. In formulating a reliable theory that would adequately describe all phenomena associated with formation and decay of such a blast wave, however, it is essential to obtain as much experimental evidence as possible concerning the other parameters characteristic of nuclear blast waves.

The Rankine-Hugoniot equations of state have been shown experimentally to be an accurate statement of the interrelations of these parameters—density, temperature (velocity of sound), particle velocity, and overpressure—for the region immediately behind the front of an ideal steep-fronted shock-tube wave. But a blast wave from a nuclear explosion can hardly be classified as ideal; depending upon burst conditions and the surface over which the pressure wave travels, it may be characterized by such irregularities as a finite or slow rise to peak overpressure, a rounded peak, and an indeterminate dissipation of overpressure as a result of precursor formation. In the light of these deviations from the ideal there has been some question whether the Rankine-Hugoniot equations are directly applicable to nonideal blast waves from nuclear explosions. Moreover, there seemed to be a need for experimental determination of these parameters in portions of the blast wave other than those immediately behind the pressure front, in the negative as well as in the positive phase.

It was believed, therefore, that a concerted effort to measure as many as possible of these parameters experimentally would not only provide valuable evidence in corroboration or refutation of the applicability of these equations to the region immediately behind the shock front but would lead to the formulation of a more accurate theoretical description of the complete blast wave from a nuclear explosion. Consequently, when plans for Operation Ivy were being drawn up, such a program of measurements became one of the primary objectives.

Initial rough estimates of the effects of superweapons,¹ such as that scheduled for Mike shot of Operation Ivy, indicated that extensive damage could be anticipated from a source other than overpressures and winds accompanying the blast wave itself, namely from the after-winds (or post-negative-phase winds) caused by the inrush of air toward the low-pressure region created by the rise of the fireball. In fact, initial predictions were that these winds would be of such velocities that they could do extensive damage over and above that wrought by the blast

*Peak overpressures on the Mike and King shots of Operation Ivy, measured by Sandia Laboratory under Project 6.1, are reported in WT-602.

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wave itself. Later theoretical studies of the problem resulted in a considerable downward revision of predicted velocities,³ and a thorough analysis by Peter et al. of the Rand Corporation³ culminated in the conclusion that these after-winds would be negligible and therefore incapable of effecting damage in their own right, a fact later borne out by field measurements.

Nevertheless, prior to completion of these theoretical analyses, the Sandia Laboratory had been asked to initiate a program to develop a group of end instruments to serve the dual purpose of measuring previously unmeasured parameters of the blast wave as well as after-winds. Since extensive measurements of positive and negative phase winds were contemplated, it was possible to adapt the same instruments for measuring after-winds. These instruments were designed in time for field tests on Operation Tumbler-Snapper,⁴ with the ultimate objective, of course, of selecting and perfecting the most promising for use on the subsequent program of Operation Ivy.

2 INSTRUMENTATION

A specific objective of these measurements was to arrive at a reasonably accurate description of the shock waves from the two experimental bursts on Operation Ivy in terms of wind or particle velocities in the positive and negative phase and the concomitant changes in temperature across the shock front as well as throughout the shock wave. It was thought that correlation of the measured values for shock winds and temperatures with corresponding measured overpressures⁵ would lead to a more realistic description of shock wave propagation. Moreover, since during original planning for Operation Ivy particular emphasis was placed on measurement of after-winds, instrumentation for measuring negative phase winds was adapted for measurement of after-winds as well. Because of the anticipated yield of Mike shot and the conditions under which both bursts on Operation Ivy were to be made, it was believed that more or less ideal circumstances would prevail for observing after-winds if they proved to be of significant magnitudes.

Instruments for use during this study were selected from the group evaluated during field tests on Operation Tumbler-Snapper. Details of their construction, principles of operation, installation, and calibration have already been discussed in the evaluation report on that project⁴ and will not be repeated here. Inasmuch as some of the same instruments were used to measure pertinent parameters of both shock winds and after-winds, these instruments are described as a group entity. The basic parameters to be measured were dynamic pressure (q), total head or total pressure (static + dynamic pressure, P_t), wind velocity (u) and speed of sound in the medium (C), and temperature (T).

Dynamic pressures were measured by means of two entirely distinct instruments, the Pitot static tube and the q -gauge (or q -tube).⁴ The Pitot static tube (Fig. 1) incorporates two Wiancko differential pressure gauges which measure the difference between total and static pressure to give a direct reading of dynamic pressure or q . A double-ended instrument, it was mounted to give readings of dynamic pressure in both the positive and negative phases of the shock wave as well as during the after-winds. It might be mentioned here that the Pitot static tubes used for this series of measurements also housed static pressure gauges for measuring side-on pressures under Project 6.1.⁵ The q -gauge (Figs. 2 and 3) also gives a direct reading of dynamic pressure but operates on a somewhat different principle; four strain gauges are mounted on a flat plate or disk whose deflection, when oriented cross-wind, is proportional to the dynamic pressure in accordance with a predetermined relation.* This sensing element is enclosed in an open-ended tube to minimize errors caused by changes in wind direction. The q -gauge also measures the dynamic pressure of both positive and negative winds.

* $D = C_D (\frac{1}{2} \rho u^2) A = C_D q A$, where D is the drag on the plate, C_D is the coefficient of drag, and A is a constant. Thus drag is a function of dynamic pressures, q .

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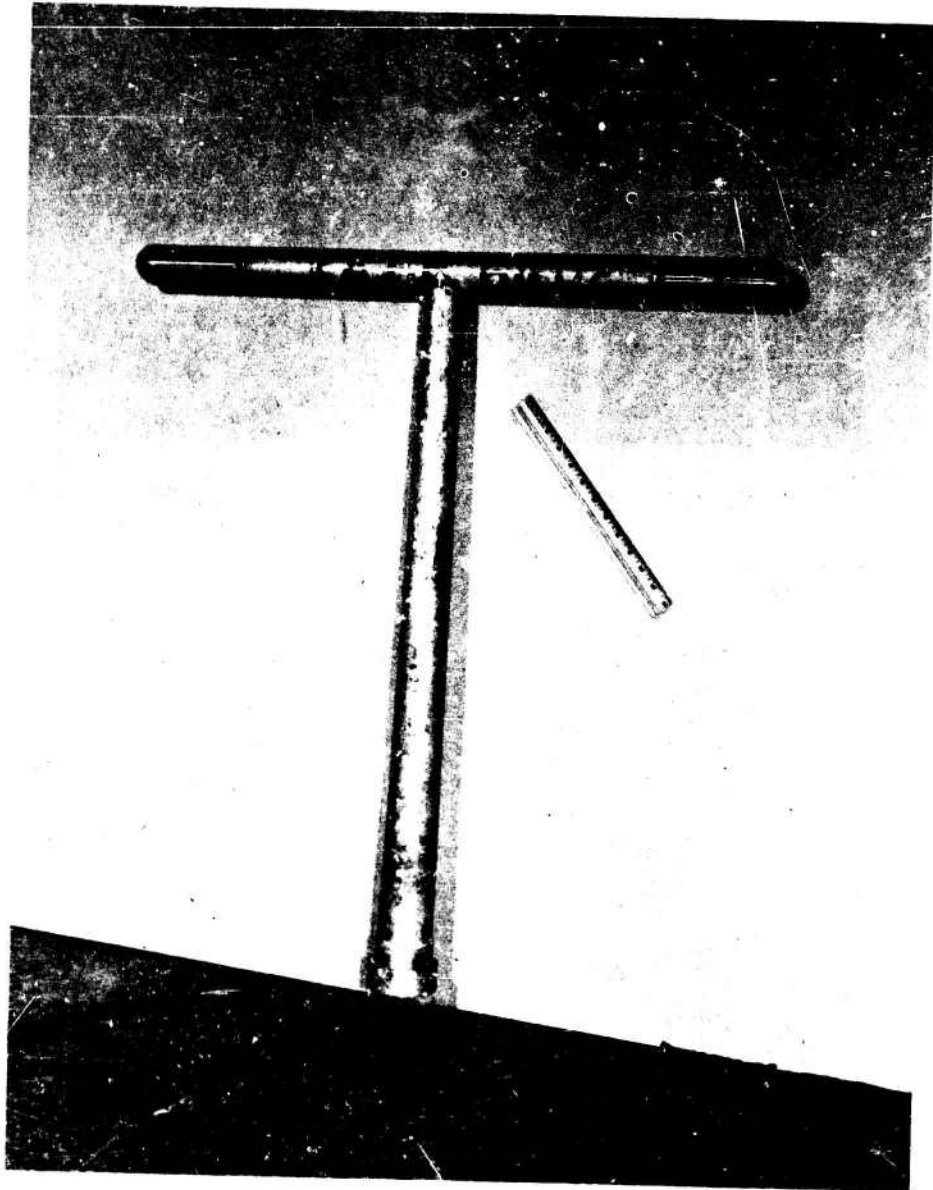


Fig. 1—Pitot static tube.

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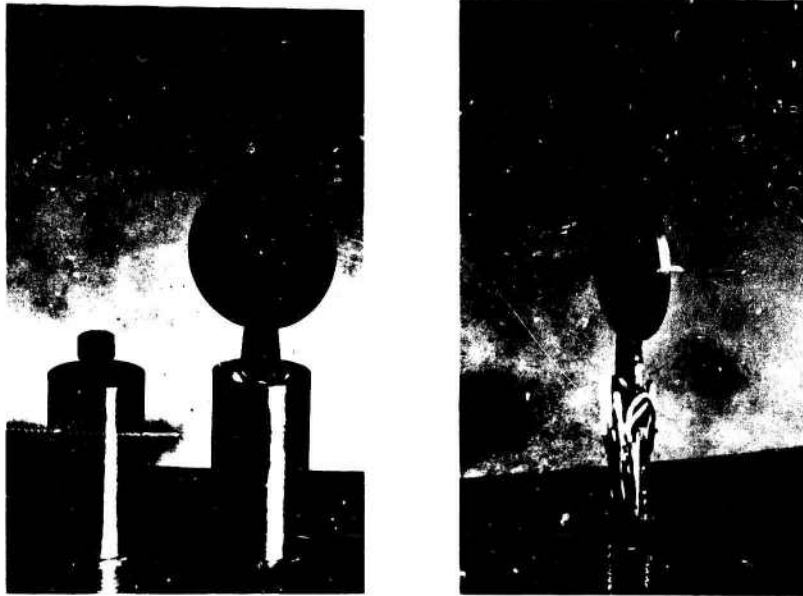


Fig. 2—q-Gauge disassembled, showing deflecting element.



Fig. 3—q-Kiel gauge combination (Kiel gauge is the upper gauge).

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Closely correlated with measurements of dynamic pressure were measurements of total head, or static + dynamic pressure. In effect these measurements provided a check on measured dynamic pressures when used in conjunction with static pressures determined at the same locations on Project 6.1. The Kiel gauge⁴ (Fig. 3), which was used at most locations (Tables 1 and 2) to obtain readings of total head, consists essentially of two Wiancko air-pressure gauges mounted inside an open-ended tube in such a manner that the sensing element sees total pressure; the gauge at one end is oriented to read total pressure in the positive phase while that at the opposite end reads total pressure in the negative phase. The encasing tube minimizes errors resulting from changes in wind direction. At the two stations closest to ground zero on Mike shot, where it was anticipated that after-winds would attain their greatest velocities and where there was a great possibility that the Kiel gauges would be blown from their mounts during passage of the positive phase of the shock wave, special after-wind gauges (Fig. 4) were installed. These were simply Wiancko air-pressure gauges⁶ mounted in the vertical face of a heavy concrete wedge and oriented to face head-on into the negative winds, thus measuring total pressure. The concrete wedge afforded the necessary protection during the positive phase of the shock wave.

The supersonic wind and sound speed indicator (Swassi)⁴ (Fig. 5) was designed specifically to measure transit times of supersonic sound pulses in the medium.* It comprises two supersonic speakers in a single mounting, used as transmitters in combination with two microphones or receivers spaced equidistantly from the speakers. Oriented at an angle of 45° with a radius through ground zero, it measures simultaneously the transit times in both the upstream and downstream directions. Using these measurements it is possible to compute directly the corresponding wind velocities and speeds of sound in the media prior to, during, and after arrival of the shock front. Furthermore, using these computed values of speed of sound, it is possible to compute correlated values of temperature.

Temperatures were also measured directly by means of the temperature gauge⁴ (Fig. 6), a resistance thermometer which utilizes the changes in resistance of an extremely fine (0.005 in. in diameter) Nilvar wire. This wire is so mounted that the high-velocity flow of the shock wave may be used to obtain a rapid rate of heat transfer between the wire and the surrounding air. Although the primary objective of this phase of the measurements was to record the changes in temperature across the shock front and throughout the shock wave and after-winds, considerable interest was also evinced in preshock temperatures resulting from thermal radiation from the fireball because of their singular importance in the study of precursor formation.^{7,8}

2.1 Blast Line for Mike Shot

Details of the locations and types of instrumentation for Mike shot are presented in Fig. 7 and Table 1. Except at the two stations nearest ground zero, the instrumentation at all stations was virtually identical. No Swassi instrumentation was installed at the farthest-out station on Parry because the predicted signal level was so low as to be almost negligible.

Spacing of the stations on this blast line was based upon estimated overpressures, which were the primary measurements along this line; pressure-measuring stations were so spaced that predicted overpressures were approximately halved at each successive station.⁵ Stations 611.01, 611.02, and 611.03 of the blast line for wind and temperature measurements conformed to this general pattern; however, at the last two stations, 611.04 and 612.01, overpressures were reduced by considerably more than half those at the preceding station. The crescent-shaped configuration of the island chain made it impossible to align all measuring stations on a

*Another velocity-of-sound device for measuring preshock temperatures is described in the AFSWP Preliminary Report on Operation Tumbler, Annex XX, entitled The Measurement of Pre-Shock Sound Velocity.

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Table 1—INSTRUMENTATION FOR MIKE SHOT

Island	Station No.	Azimuth (from north)	Distance from ground zero, ft	Shock wind instrumentation	After-wind instrumentation	Temperature instrumentation	Shelter
Bogairikk	615.01	72°44'45"	5,900	None	Wiancko air pressure gauge oriented to measure to-tal head	None	600(A)
Bogon	615.02	73°01'08"	8,250	None	Wiancko air pressure gauge oriented to measure to-tal head	None	600(B)
Engebi	611.01	93°16'38"	15,900	Pitot static tube Swassi* q-Gauge Kiel gauge	Pitot static tube Swassi	Temperature gauge Swassi	601(A) 601(A) 601(A) 601(A)
Muzin	611.02	105°51'31"	21,412	Pitot static tube Swassi q-Gauge Kiel gauge	Pitot static tube Swassi	Temperature gauge Swassi	602(A) 602(A) 602(A) 602(A)
Bokonaarappu	611.03	111°18'50"	30,130	Pitot static tube Swassi q-Gauge Kiel gauge	Pitot static tube Swassi	Temperature gauge Swassi	603(A) 603(A) 603(B) 603(A)
Aomon	611.04	109°55'37"	47,574	Pitot static tube Swassi q-Gauge Kiel gauge	Pitot static tube Swassi	Temperature gauge Swassi	604(A) 604(A) 604(B) 604(A)
Parry	612.01	144°59'56"	114,240	Pitot static tube q-Gauge Kiel gauge	Pitot static tube	Temperature gauge	606(A) 606(A) 606(A)

*Supersonic wind and sound speed indicator.

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single radial line through ground zero, and the instrument stations were at various azimuths from the north reference line passing through ground zero (Table 1). As can be seen from the map in Fig. 7 the blast wave traveled essentially all of its path across water before reaching most of these stations.

With the exception of the Swassi, which was oriented at an angle of 45° with a radius passing through ground zero, all instruments were oriented to face directly into ground zero. Mounting of the instruments was conventional; because the Swassi had to be mounted on goal-post type towers (Fig. 5), the other wind and temperature measuring instruments at Stations 611.01, 611.02, 611.03, and 611.04 were placed on the same mount. At Station 612.01, where no Swassi instrumentation was used, all instruments were mounted on a 15-ft single pipe stand (Fig. 8). Heights of the instruments above the ground are listed in Table 2. As mentioned previously, the after-wind gauges at Stations 615.01 and 615.02 were mounted in specially reinforced concrete wedges (Fig. 4) approximately 2 ft off the ground. These gauges were, of course, oriented so as to face away from ground zero or directly into the negative winds.

Table 2—HEIGHTS OF INSTRUMENTS ABOVE GROUND

Instrument	Height, ft	
	On goal-post tower	On single pipe stand
Swassi (transmitter-receiver openings)	16.5 (approx)	
q-Kiel gauge combination	13.5	14.5
Pitot static tube	13.5	14.5
Temperature gauge	14.5	13.5

Power to all gauges except the Swassi was supplied by a standard Consolidated Engineering Corporation 3-kc carrier system; the Swassi had its own power supply, operated either from batteries or from 110-volt, 60-cps alternating current. Outputs of the gauges were recorded on magnetic tape by a multichannel Ampex recording system.⁹ Recording shelters were placed at convenient locations to serve all instrumentation (Table 1).

2.2 Blast Line for King Shot

The map in Fig. 9 shows station locations for the blast line on King shot with relation to actual and intended ground zeros. Pertinent details of the intended distances from ground zero and types of instrumentation are presented in Table 3. The first three stations were all on the island of Runit, while the fourth was on the northern tip of Parry at the same location as the farthest station on Mike shot. As on Mike shot, spacing of the stations was based upon predicted overpressures, and the same general pattern was followed. The shapes of the islands themselves and the varying amounts of interspersed water surface resulted in a considerable variability in the ratios of land to water in the path traversed by the blast wave to the various stations.

Orientation and mounting of the instrumentation was identical to that used on Mike shot. Single pipe stands were used at Stations 618 and 612.02, and goal-post towers were used at Stations 619.01 and 619.02. The power and recording systems were the same, the gauges on Runit being served by Shelter 605 on Runit and those on Parry by Shelter 606 on Parry.

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Fig. 4—After-wind (Wiancko) gauge mounted in concrete wedge.

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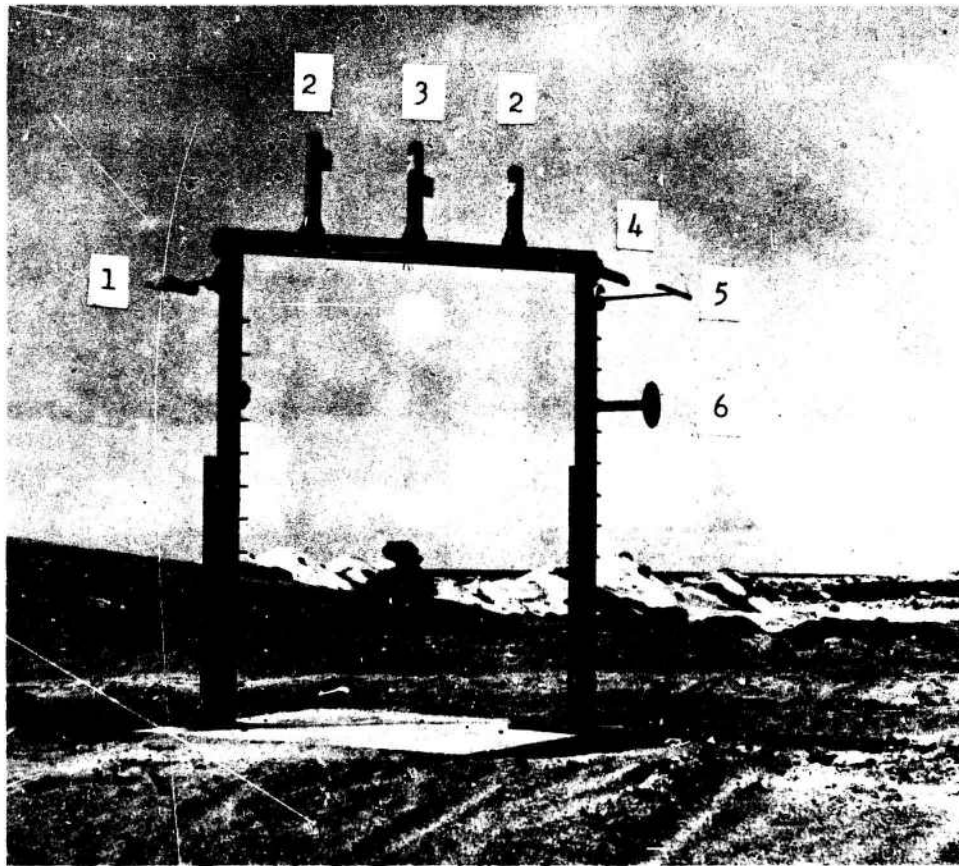


Fig. 5—15-ft goal-post tower, showing (1) q-Kiel gauge, (2) Swassi receiver, (3) Swassi transmitter, (4) temperature gauge, (5) Pitot gauge, and (6) side-on gauge.

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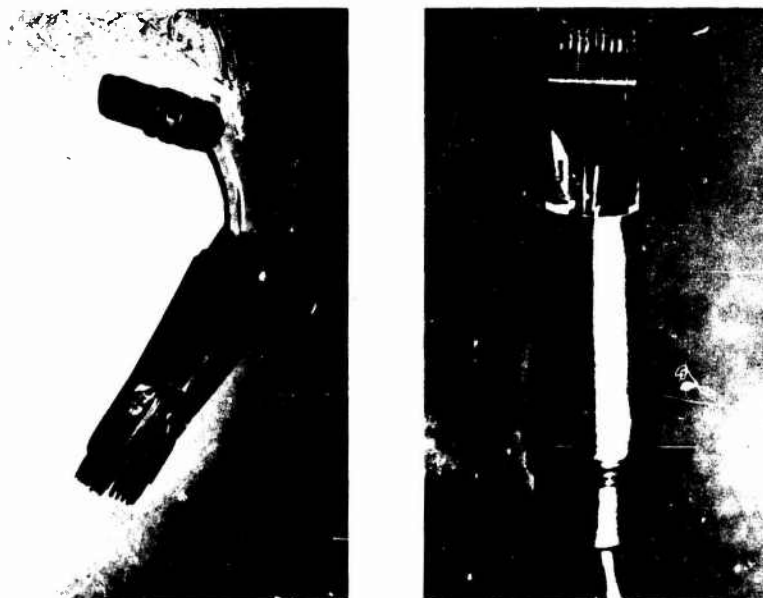


Fig. 6—Close-up views of the temperature gauge (sensing element is suspended from the tips of the prongs).

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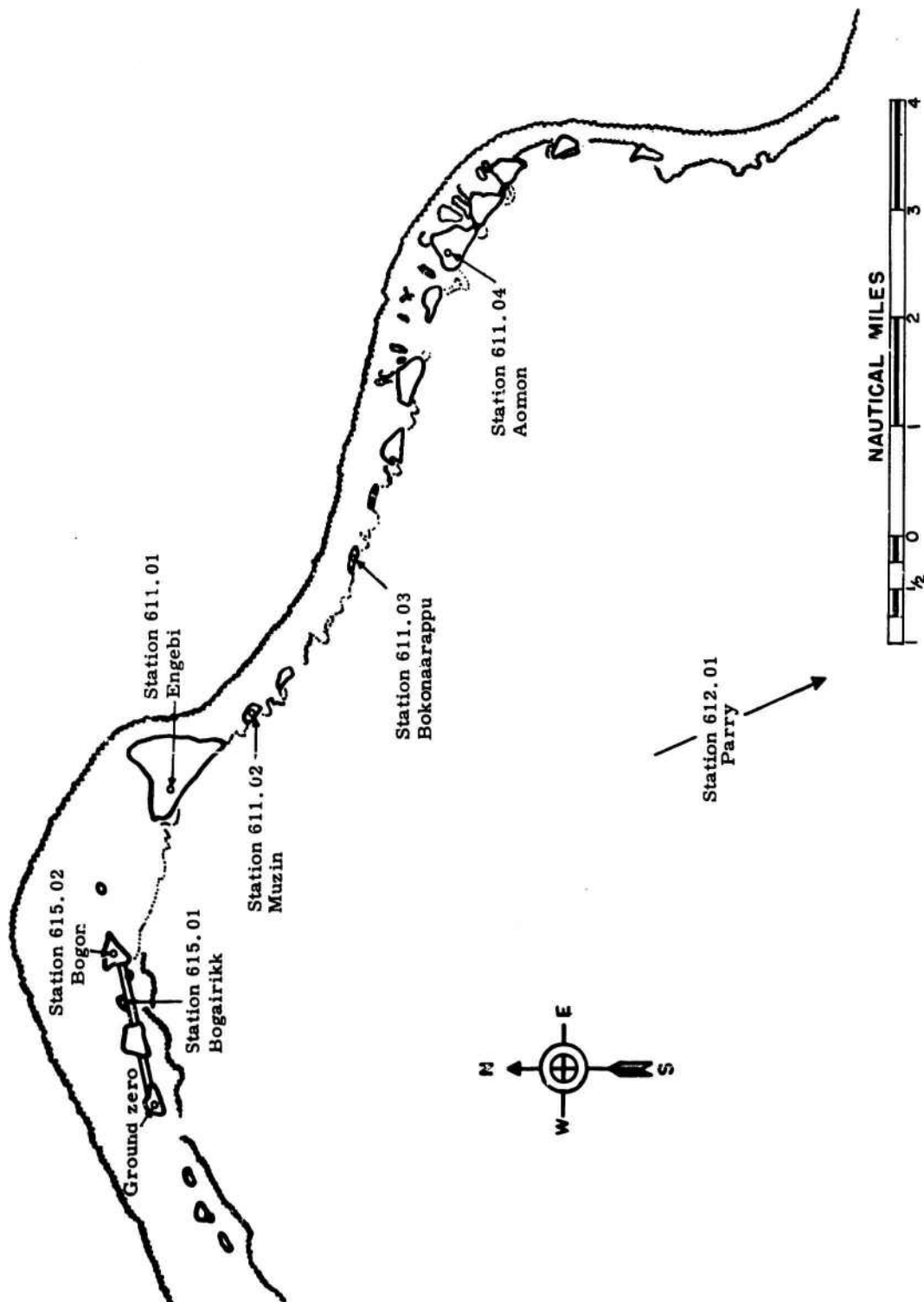


Fig. 7 — Blast line for Mike shot.

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Fig. 8—Single pipe stand, showing mounting of the temperature gauge. The q-Kiel combination and the Pitot static tube are already in place.

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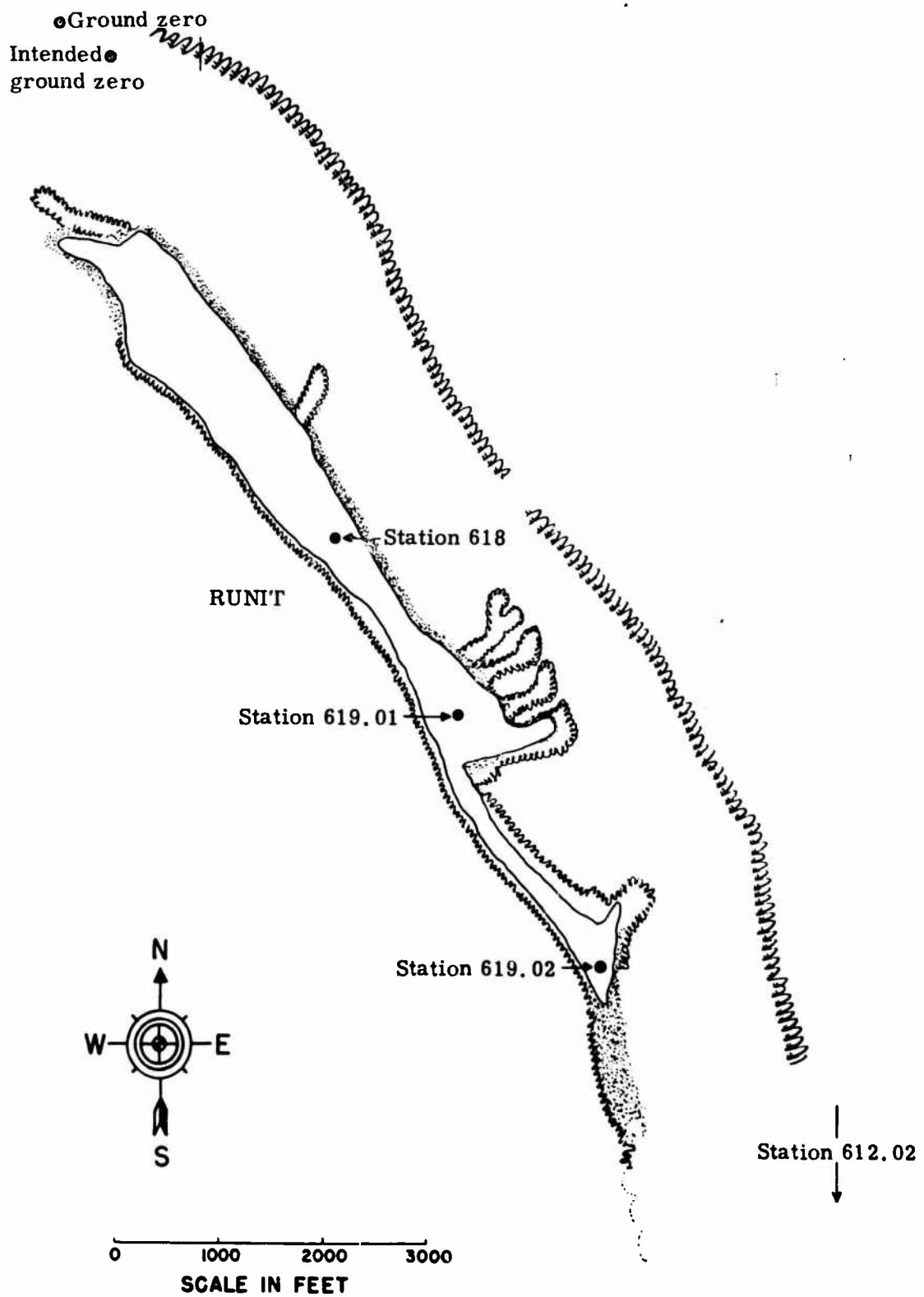


Fig. 9—Blast line for King shot.

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Table 3 — INSTRUMENTATION FOR KING SHOT

Island	Station No.	Distance from ground zero, ft	Shock wind instrumentation	After-wind instrumentation	Temperature instrumentation
Runit	618	5,491	Pitot static tube	Pitot static tube	None
	619.01	7,502	Pitot static tube Swassi	Pitot static tube Swassi	Swassi
	619.02	10,188	Pitot static tube Swassi	Pitot static tube Swassi	Swassi
Parry	612.02	55,132	Pitot static tube q-Gauge Kiel gauge	Pitot static tube	Temperature gauge

3 PERFORMANCE OF INSTRUMENTATION AND RECORDING SYSTEM

Of the 42 wind and temperature measurements attempted on Mike shot, 21 were completely successful and 4 partially so; approximately half the failures to obtain any intelligence at all were attributable to unforeseeable failures of the recording equipment as discussed below. A much better record was established on King shot, for of the 16 channels of information sought, only 6 partial failures and no complete failures took place. It is believed, therefore, that the conclusions reached in this report are based on ample experimental evidence.

Several unpredictable failures of the gauge and recording system did make it mandatory, however, to exercise a certain amount of personal judgment in analyzing the experimental data from both Mike and King shots.

An inherent and undesirable characteristic of the Ampex recording system as used for these measurements was the tendency toward zero drift in the playback of the record. It was necessary to use considerable arbitrary judgment in establishing a base line for records from all gauges on both Mike and King shots.

3.1 Mike Shot

Of perhaps the most serious consequence was the failure of 3 of the 11 recorders used on Mike shot to start at all because the brakes on the tape transport system jammed. These brakes comprised asbestos brake bands surrounding soft iron brake drums; the extremely high moisture content of the air in the recording shelters prior to Mike shot apparently caused the brake bands to swell and the drums to rust, with the result that the mechanism was jammed prior to operation.

Complete records were obtained from Pitot static tubes at three locations — Stations 611.02, 611.04, and 612.01. That at Station 611.01 was apparently damaged during the negative phase of the blast wave, and, although the records for the positive phase were unaffected, those for the negative phase are probably unreliable except for peak dynamic pressure.

The q-gauges at two locations, Stations 611.01 and 611.04, likewise gave highly satisfactory records, but the signal level at Station 612.01 was apparently too low to be recorded.

Except at Station 611.03, the Kiel gauge performed satisfactorily, giving good readings in both the positive and negative phases. That at Station 611.01 gave only a peak reading in the positive phase when the front pressure gauge failed soon after passage of the shock front, but the record for the negative phase was complete.

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Records from the Swassi were somewhat disappointing in that a complete record was obtained at only one station, 611.02. At Station 611.01 the drivers failed to start, and at the other stations the recorders failed.

The temperature gauge gave satisfactory records at Stations 611.01 and 611.02.

3.2 King Shot

In the interval between Mike and King shots steps were taken to obviate the type of recorder failure that proved so troublesome on Mike shot. The brake bands were removed and the brakes fixed so that the recorders ran free. Actually the brakes were not used during operation of the recorder, the Ampex recorder having been designed for other applications in which it is desirable to start and stop the recording system quickly. Too, because the number of recorders needed on King shot was not so great as on the previous set of measurements, it was possible to take the added precaution of installing dual or back-up recorders; since both recorders ran during the test, if one failed, a record was obtained on the other.

Thus, although no difficulty was experienced with failure of the recorders on King shot, a problem was posed as a result of the tape wow or fluctuation in the speed at which the tape passed the recording heads when the shock front struck the shelter. Although this wow occurred at the beginnings of some of the records and at the crossover points on others, it did happen that some of the gauges on the blast line were at balance during this period and the signal appearing on these particular channels could be attributable solely to tape wow. These records that recorded wow alone could thus be used as a standard for comparison in subtracting the wow from the channels which did record gauge signals during this period, and it was possible to read the records from the wind and temperature gauges despite the interference from tape wow.

The Pitot static tube performed satisfactorily at all except the first station, 618, where it was blown from its mount. Although a peak reading was obtained, it is not believed to be realistic. Satisfactory records in both the positive and negative phases were obtained at Stations 619.01 and 619.02, and in the positive phase at Station 612.02. The signal level was apparently too low to give a record in the negative phase at Station 612.02.

The single q-Kiel combination at Station 612.02 gave satisfactory records in both the positive and negative phases. However, because the wire broke soon after arrival of the shock front, the temperature gauge at this station gave a peak reading only.

Because noise in the blast wave triggered the interval timer, the Swassi at all stations on King shot failed to give any readings during the passage of the blast wave.

4 DETERMINATION OF SET RANGES FOR THE WIND AND TEMPERATURE GAUGES

Selection of realistic set ranges for all blast-line measurements on Mike shot was complicated by the fact of its unprecedentedly large yield and the inherent difficulty in predicting this yield with any exactitude. Prediction of peak overpressures,⁶ normally an established empirical procedure based upon ample supporting evidence from previous experimental measurements, was necessarily somewhat arbitrary in view of the uncertainty of the yield and the fact that for all practical considerations this shot was to be a surface burst over water—the first ever attempted.* Prediction of overpressures on King shot was, of course, a matter of routine.

Prediction of set ranges for the wind and temperature instrumentation on both Mike and King shots was further complicated by the fact that there was comparatively little previous experience or applicable experimental data upon which to draw. Peak positive values for the various parameters to be measured could be based to a certain extent upon earlier measure-

*A previous surface burst was made over land on the Jangle Sugar shot.

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ments on Operation Tumbler-Snapper.⁴ But set ranges for the negative phase and after-winds were quite another matter, however; the dearth of theoretical knowledge regarding the behavior of the negative winds accompanying and following the shock wave made it necessary to temper estimates of set range in the light of anticipated damage potentialities of the after-winds. In other words, primary emphasis was to be placed upon measurement of after-winds of damage-producing velocities if after-winds of such magnitude occurred, in the knowledge that negative phase winds could still be measured by the same instruments even though the set ranges were high. Thus it was believed to be desirable to err on the side of placing the set ranges too high rather than too low; if the after-winds did prove to be insignificant (not capable of producing damage in their own right), no particularly valuable information was to be lost.

The procedure followed in computing set ranges may perhaps best be illustrated by using a specific example. Since the Pitot static tube is a double-ended instrument designed to measure dynamic pressures in the positive phase as well as during the negative winds, it was chosen as exemplary. If we discuss first the front differential gauge, which measures dynamic pressure in the positive phase of the blast wave, the quantity to be measured may be expressed as

$$q = \frac{1}{2} \rho u^2 \left(1 + \frac{M^2}{4} + \frac{M^4}{40} + \dots \right)$$

where u = peak particle velocity

ρ = density

M = Mach number of flow

But for all measurements reported here M^2 is small enough that the compressibility factor may be dropped,* giving

$$q = \frac{1}{2} \rho u^2 \quad (1)$$

Since, in accordance with the Rankine-Hugoniot equations,

$$u^2 = C_0^2 \frac{25}{7} \frac{Z^2}{7 + 6Z} \quad (2)$$

and

$$\rho = \rho_0 \frac{7 + 6Z}{7 + Z}$$

Eq. 1 becomes

$$q = \frac{25}{14} \rho_0 C_0^2 \frac{Z^2}{7 + Z} \quad (3)$$

where C_0 = ambient speed of sound

ρ_0 = ambient density

$Z = \Delta P / P_0$

ΔP = peak overpressure

P_0 = ambient pressure

*At 20 psi the compressibility factor makes a difference of 4 per cent in the value of q .

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Thus the dynamic pressure, q , can be computed in terms of the predicted overpressure and the ambient conditions at the specific location.

Estimation of set range for the back differential gauge of the Pitot static tube was based upon the thesis that to be capable of producing damage the after-winds would have to attain a peak particle velocity of at least 600 mph within a distance of 1 mile from their starting point and that this velocity would fall off as $1/r$ at successive stations.* Because it seemed logical to assume that the density would return to ambient before the after-winds started, Eq. 1 ($\rho = \rho_0$) could again be applied to arrive at dynamic pressures for the after-winds based upon probable maximum values of peak particle velocity. All assumptions used in computing set ranges for after-winds were based upon a maximum predicted yield of 40 Mt.

Since the q -gauge recorded only one channel of information, its set range was naturally determined by the peak values of dynamic pressure in the positive phase, calculated as for the front differential gauge of the Pitot static tube. For this reason it was not particularly well adapted to measure dynamic pressures in the negative phase.

Having made the predictions of dynamic pressure for the Pitot static tube, it was a simple matter to arrive at set ranges for the positive phase element of the Kiel gauge by addition of the predicted static and dynamic pressures. And since for all practical considerations it might be assumed that the static pressure had returned to the ambient value before the after-winds began, set ranges for the back element of the Kiel gauge would be essentially the dynamic pressures (Eq. 4) as determined from predicted after-wind velocities.

Set ranges for the Swassi, which involved both peak particle velocity and speed of sound in the medium, were again computed from the predicted peak overpressures and measured ambient conditions by use of Eq. 2 and the following Rankine-Hugoniot equation:

$$\frac{C^2}{C_0^2} = \frac{T}{T_0} = \frac{(1+Z)(7+Z)}{7+6Z} \quad (4)$$

where C = speed of sound behind the shock front

T = temperature behind the shock front

T_0 = ambient temperature

It should be noted that the temperature gauge does not measure the true temperature of the air in the shock wave but rather stagnation temperature, T_s , which may be expressed in terms of T by:

$$T_s = T(1 + 0.2 M^2) \quad (5)$$

where M is the Mach number behind the shock front and may be expressed as u/C (Eqs. 2 and 4). From Eqs. 2, 4, and 5, then, stagnation temperature may be expressed in terms of overpressure and ambient temperature and pressure as

$$T_s = T_0 \frac{(7+Z)(1+Z) + 5Z^2/7}{(7+6Z)} \quad (6)$$

Set ranges for the temperature gauge were calculated from Eq. 6.

*This premise is effectively a compromise between early predicted maxima for the anticipated after-winds from Mike shot,^{1,2} on which after-winds were expected to be of critical magnitudes. No cognizance was taken, in making these estimates of set range, of the analysis of Peter et al.,³ which was received too late to be of use in estimating set ranges. Too, estimated after-winds on King shot were not expected to be of damaging velocities.

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5 PRESENTATION AND ANALYSIS OF RESULTS

5.1 Mike Shot

Data from the wind and temperature measurements in the positive and negative phases of the blast wave are presented in tabular form in Tables 4 to 6 and in graphical form in Figs. 10 to 23. No entry was made in the tables for stations at which no usable data were obtained.

Peak dynamic pressures in the positive phase, as measured by the Pitot static tube and the q-gauge, are plotted in Fig. 10; the reference curve of dynamic pressures vs distance was based upon dynamic pressures computed from the measured overpressures at these same stations.⁵ It is believed that measured peak values of static and dynamic pressure and total head are subject to no more than 10 per cent error except for the dynamic pressure as measured by the q-gauge, which may be as much as 20 per cent in error.⁴ Note that at the stations closer to ground zero agreement of measured and calculated dynamic pressure was within the range of experimental error. The higher measured values at the more remote stations are believed to be realistic, however, particularly in the light of the complete agreement of the measurements of the Pitot static tube and the q-gauge at Station 611.04. The rounded peaks of the pressure-time profiles at the more distant stations may have some bearing on the divergence of these measured values from the reference curve. On this plot the hurricane region has also been delineated to give a better feel for the magnitudes of the dynamic pressures measured; wind velocities in the shaded area range from 75 to 150 mph at ambient density conditions. A graph of wind velocity vs dynamic pressure is presented in Fig. 11. Durations of the positive phase of dynamic pressure (positive phase winds) are also shown in Fig. 10.

Dynamic pressures at individual stations are plotted against time in Figs. 12 to 14. The peculiarly shaped spike on the curve for the Pitot static tube at Station 612.01 is possibly attributable to noise resulting from the fact that the signal level was very low for the set range of this gauge. It might also be pointed out that a zero shift seems to have taken place on the record for the q-gauge at Station 611.04. Except for these irregularities the waveforms of the dynamic pressure-time curves for the positive phase seem to be quite orthodox, however.

Peak dynamic pressures in the negative phase, as measured by the Pitot static tube, are plotted against distance from ground zero in Fig. 15. The corresponding pressure-time profiles are presented as Figs. 16 and 17. Although the dynamic pressures are, of course, positive pressures, they are plotted here as though they were negative quantities to emphasize the fact that these readings are taken in the negative phase. Because there was some question whether the peak negative pressure as read from the curve for Station 611.01 on Engebi was a true value, this curve was compared with that for Station 611.02, the next station on the blast line (Fig. 16). Since the dynamic pressures in the negative phase would be expected to reach their peak values in less time (after the crossover into the negative phase) at the closer stations than at the more distant stations, examination of Fig. 16 would indicate that the peak attained at Station 611.01 is a true one.

In lieu of a proved theoretical or empirical check of the magnitude of the peak dynamic pressures in the negative phase, it was decided, as a matter of curiosity, to apply the Rankine-Hugoniot equation (Eq. 3), substituting the measured maximum negative overpressure at each station for ΔP . Actually the agreement between measured and calculated q's was reasonably close at the two stations nearer ground zero, whereas at the farther stations the measured q's were considerably higher than the calculated values.

Durations of the positive phase winds as recorded by the Pitot static tube are plotted against distance from ground zero in Fig. 10. Inasmuch as the duration taken from the q-gauge record at Station 611.01 seemed doubtful and no q-gauge record was obtained at Stations 611.02 and 612.01, it seemed legitimate to base this curve on the differential pressure readings from the Pitot static tube alone. The fact that positive phase durations of the winds were in rather close agreement with the durations of the positive phase overpressures on Mike shot, except at Station 611.04, would seem to corroborate similar observations on Operation Tumbler-Snap-

(Text continues on page 44.)

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Table 4—DYNAMIC PRESSURE, MIKE SHOT

Positive Phase							
Island	Station No.	Distance from ground zero, ft	Peak static overpressure, psi	Peak dynamic pressure, psi	Peak dynamic pressure,* psi	Duration of positive winds, sec	Duration of positive overpressure, sec
Engebi	611.01	15,900	20.5	8.4†	8.1	4.8	4.6
			20.5	9.8†	8.1	1.3	4.6
Mulin	611.02	21,412	12.3	2.9†	3.1	5.9	6.3
Aomon	611.04	47,574	2.71	0.20†	0.16	13.9	9.5
			2.71	0.20†	0.16	11.9	9.5
Parry	612.01	114,240	0.48	0.01†	0.005	16.5	16.3

Negative Phase							
Island	Station No.	Distance from ground zero, ft	Peak negative overpressure, psi	Peak negative pressure, psi	Peak dynamic pressure,† psi	Duration of negative winds, sec	Duration of negative overpressure, sec
Engebi	611.01	15,900	2.15		0.15		21.5
Mulin	611.02	21,412	1.25		0.06	25	25.0
Aomon	611.04	47,574	0.58		0.02	29	29.5
Parry	612.01	114,240	0.14		0.004		27.0

*Calculated from overpressure.
†Pitot static tube.
‡q-Gauge.

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Table 5 — TOTAL HEAD,* MIKE SHOT

		Positive Phase					
Island	Station No.	Distance from ground zero, ft	Peak static overpressure, psi		Peak dynamic pressure, psi	Duration of positive phase of static overpressure, sec	
			psi	psi		psi	sec
Engeb1	611.01	15,900	20.5	31.4	8.4	4.6	
Muzin	611.02	21,412	12.3	13.10	2.9	6.3	5.3
Aomon	611.04	47,574	2.71	2.73	0.20	9.5	9.6
Parry	612.01	114,240	0.48	0.50	0.01	16.3	16.1

		Negative Phase					
Island	Station No.	Distance from ground zero, ft	Peak negative overpressure, psi		Peak dynamic pressure, psi	Duration of negative phase of static overpressure, sec	
			psi	psi		psi	sec
Engeb1	611.01	15,900	2.15	2.10	0.15	21.5	30
Muzin	611.02	21,412	1.25	1.54	0.06	25	31
Aomon	611.04	47,574	0.58	0.41	0.02	29.5	29.5
Parry	612.01	114,240	0.14	0.16	0.004	27	31

*Static overpressure plus dynamic pressure as measured by the Kiel gauge.

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Table 6—AIR TEMPERATURE, MIKE SHOT

Island	Station No.	Distance from ground zero, ft	Peak overpressure, psi	T at zero time, °C	ΔT prior to shock arrival, °C	ΔT in positive phase of shock, °C	ΔT calculated from measured overpressure, °C
Engeb1	611.01	15,900	20.5	30	+80	+184	+152
Muzin	611.02	21,412	12.3	30	0	+88	+70
Parry	612.01	114,240	0.48	30	0		

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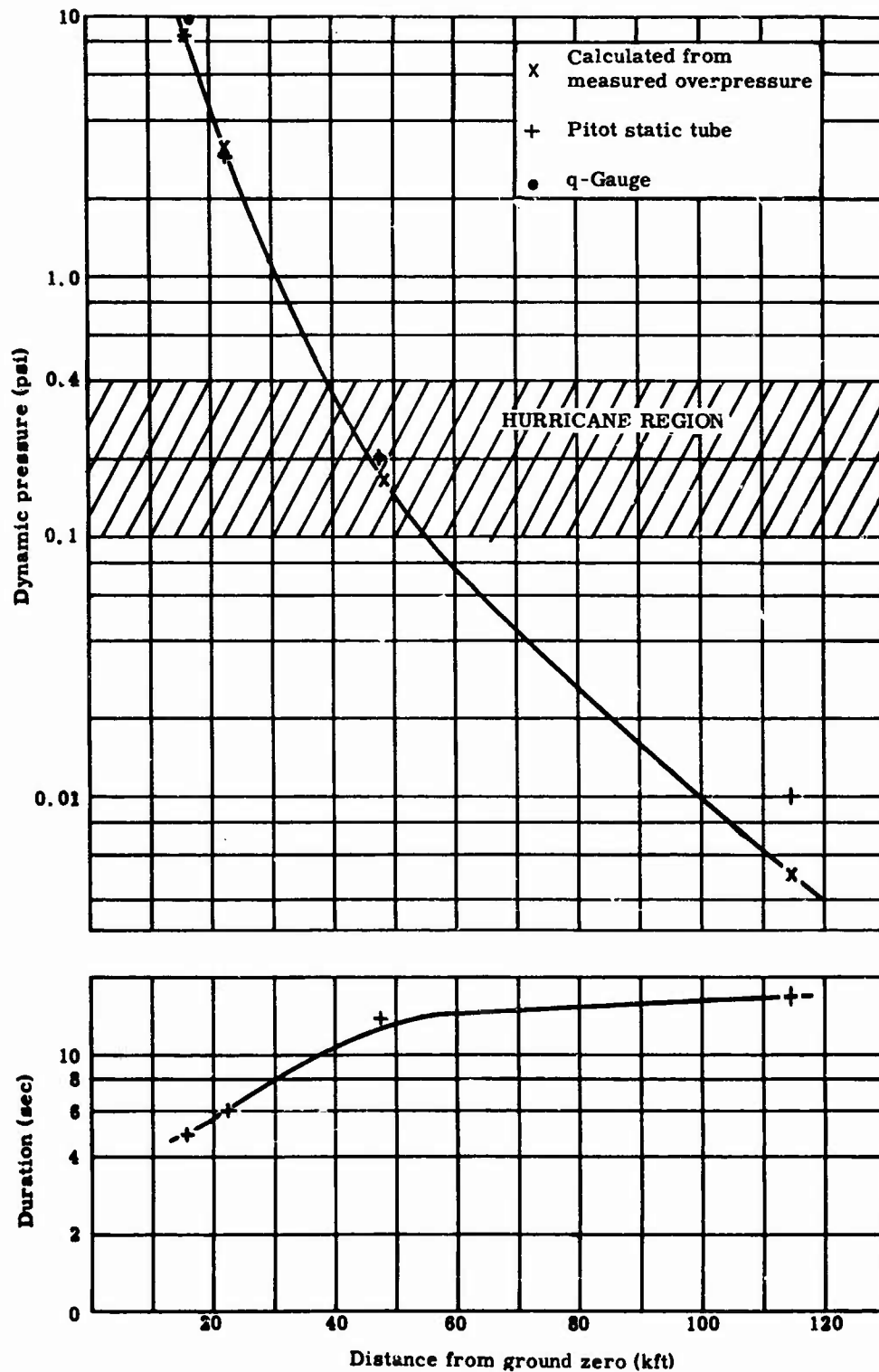
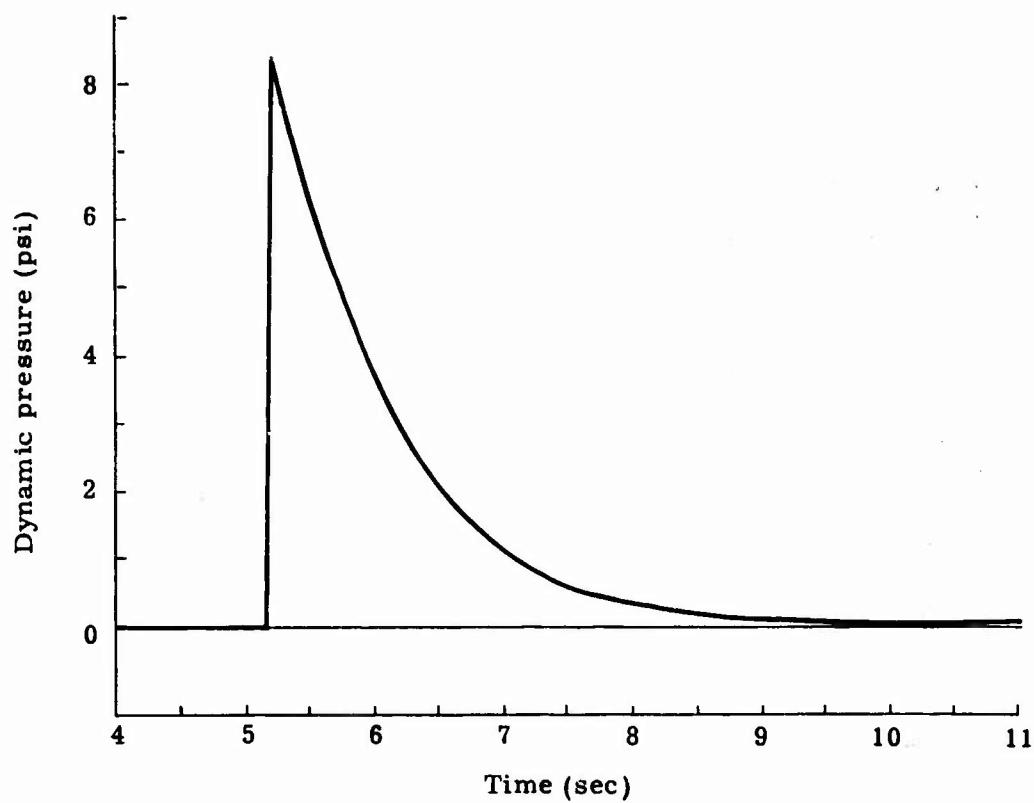
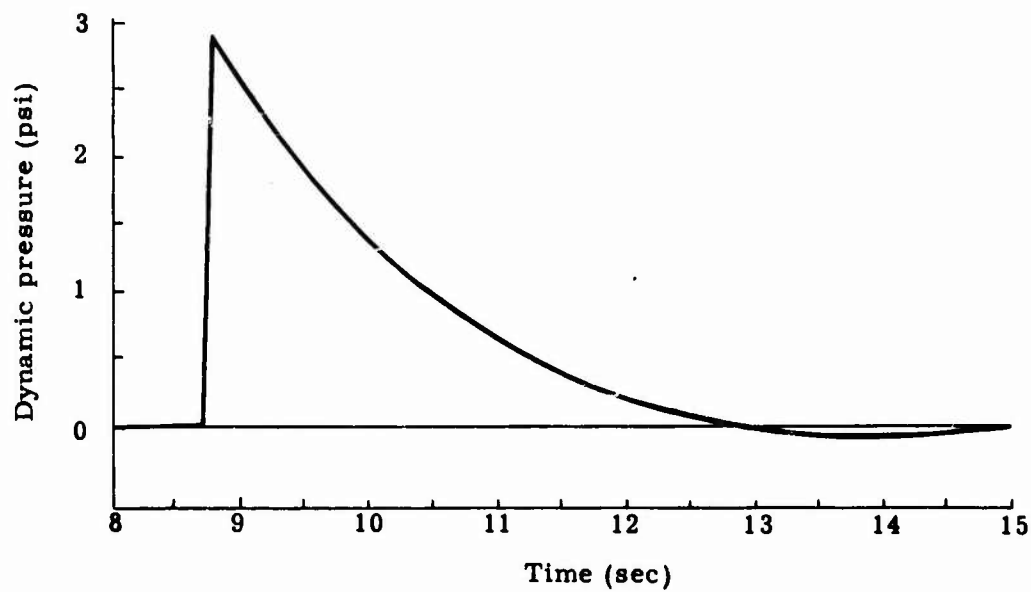


Fig. 10—Dynamic pressure and duration vs distance from ground zero (positive phase), Mike shot.

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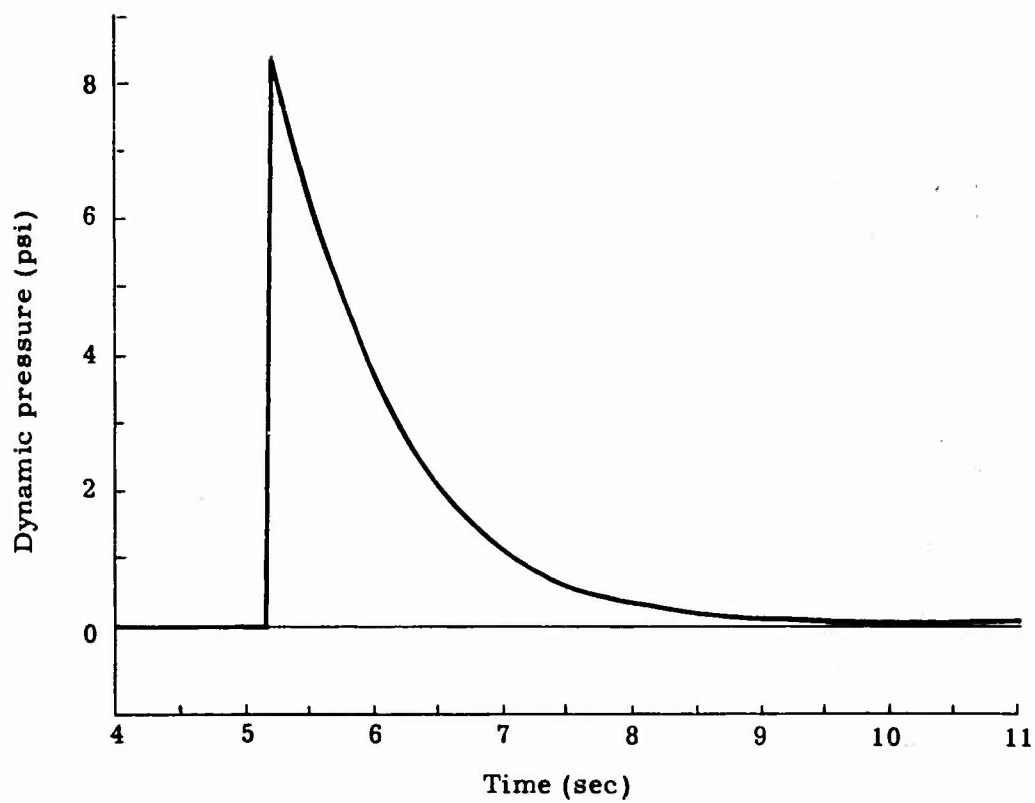
Station 611.01 (Engebi) (Pitot static tube)



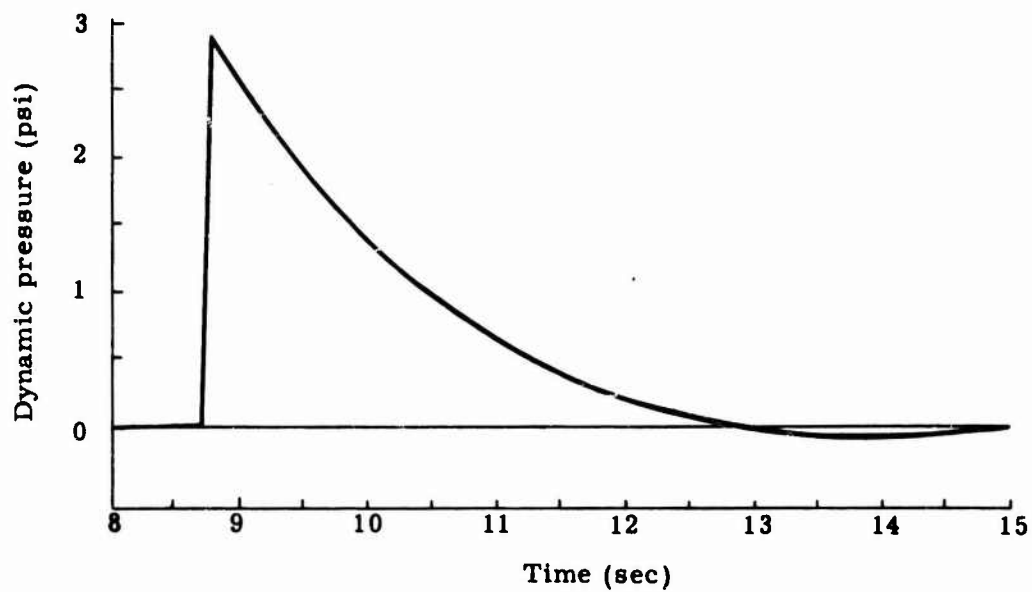
Station 611.02 (Muzin) (Pitot static tube)

Fig. 12—Dynamic pressure-time profiles, Pitot static tube, Stations 611.01 and 611.02 (positive phase), Mike shot.

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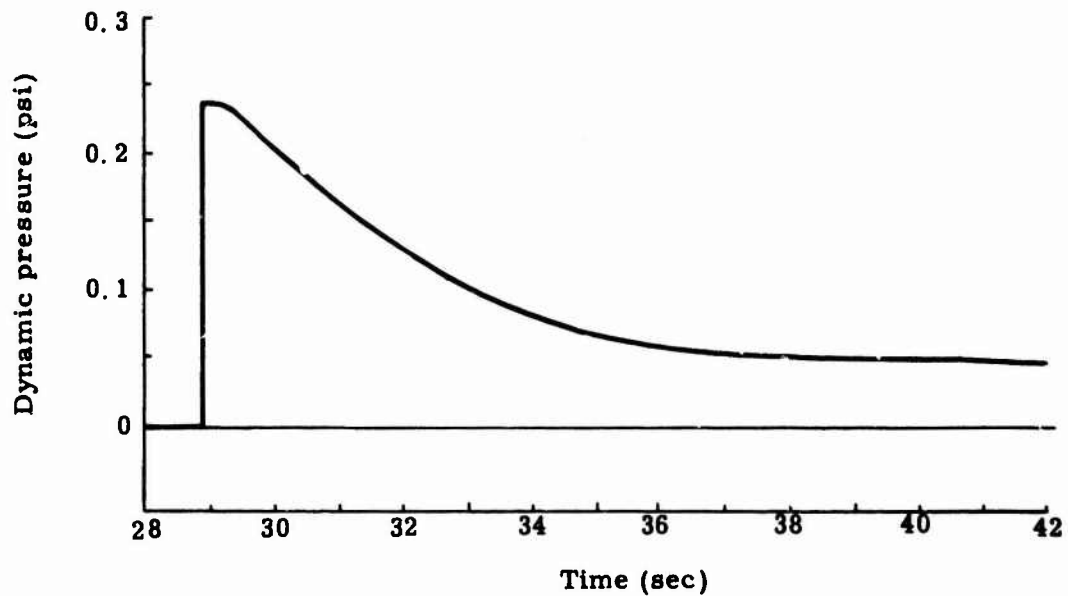
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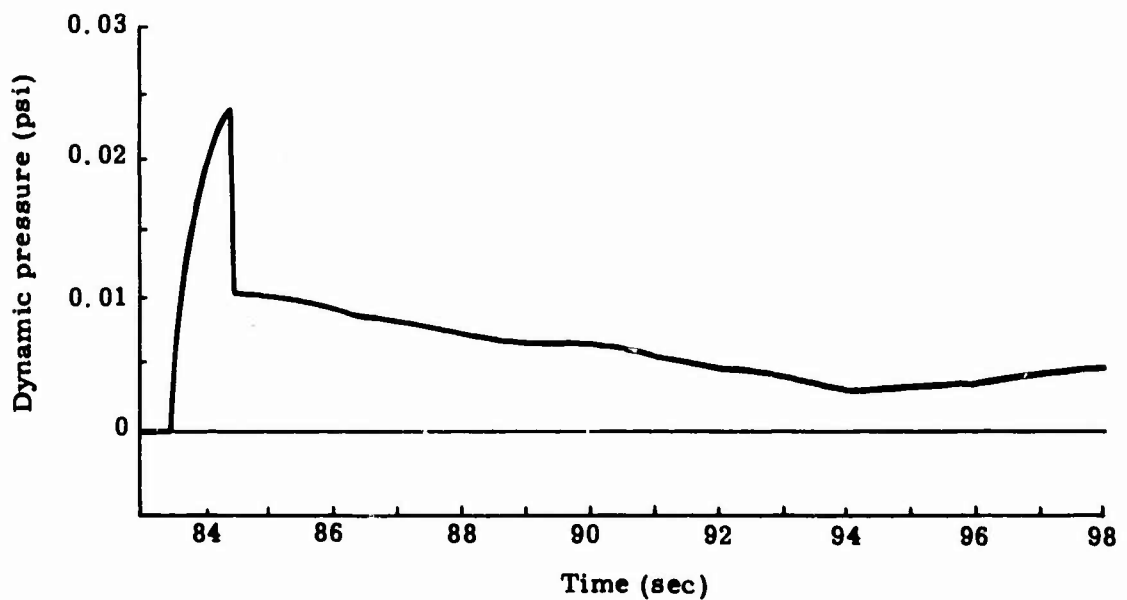
Station 611.02 (Muzin) (Pitot static tube)

Fig. 12—Dynamic pressure-time profiles, Pitot static tube, Stations 611.01 and 611.02 (positive phase), Mike shot.

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Station 611.04 (Aomon) (Pitot static tube)



Station 612.01 (Parry) (Pitot static tube)

Fig. 13—Dynamic pressure-time profiles. Pitot static tube, Stations 611.04 and 612.01 (positive phase), Mike shot.

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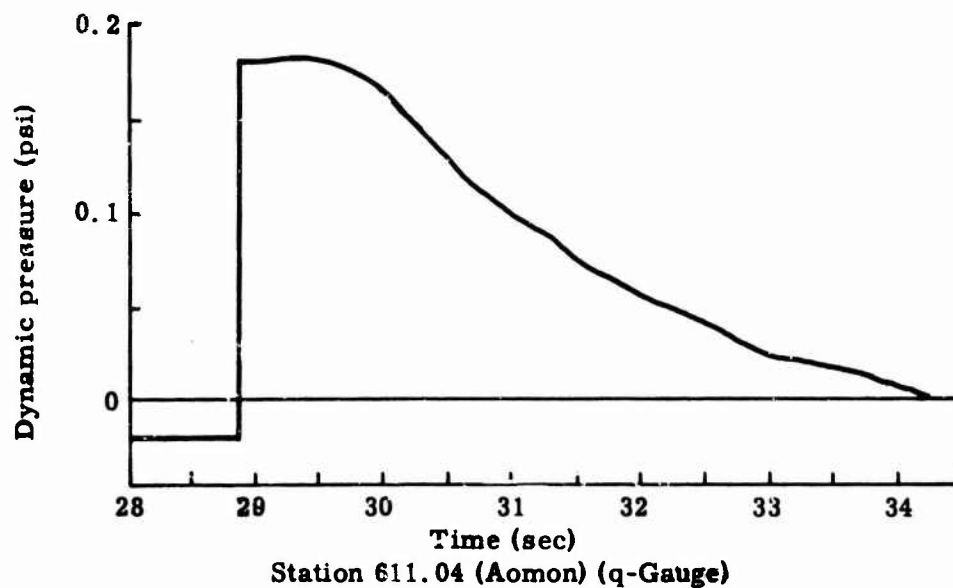
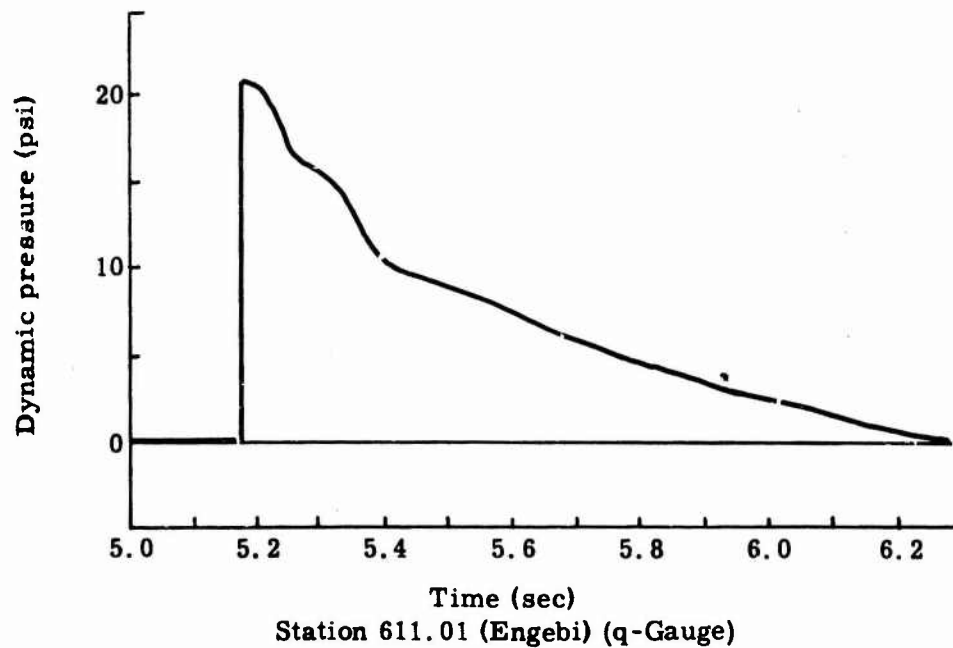


Fig. 14—Dynamic pressure-time profiles, q-gauge, Stations 611.01 and 611.04 (positive phase), Mike shot.

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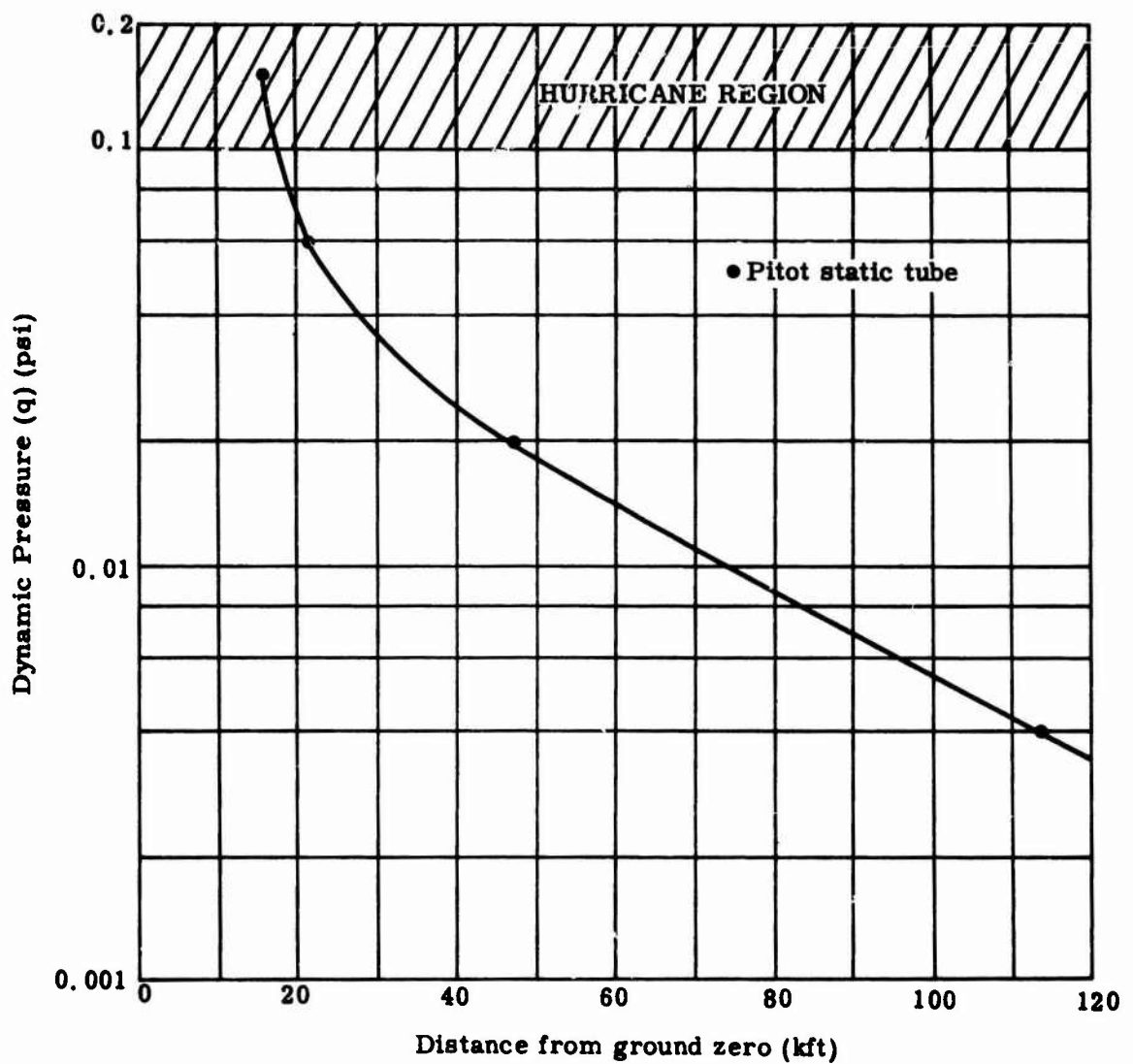


Fig. 15—Dynamic pressure vs distance from ground zero (negative phase), Mike shot.

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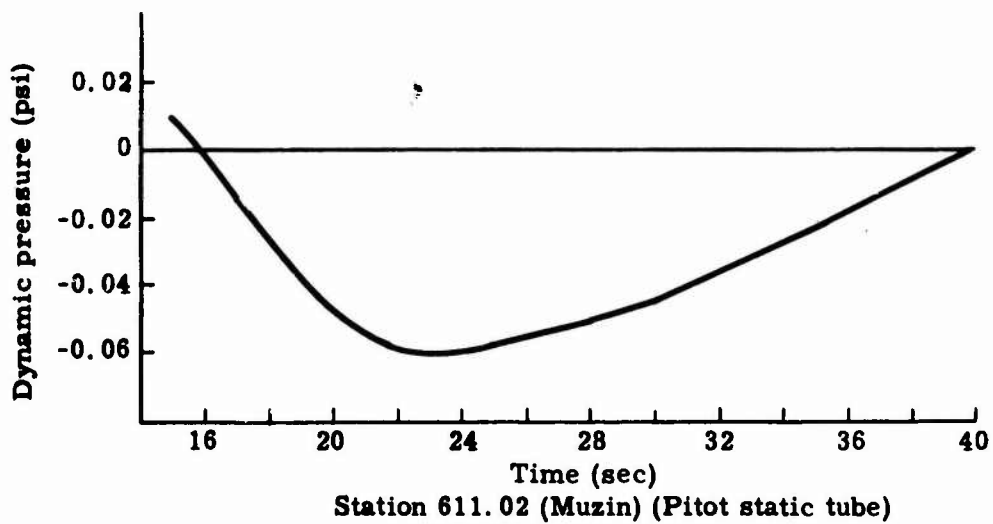
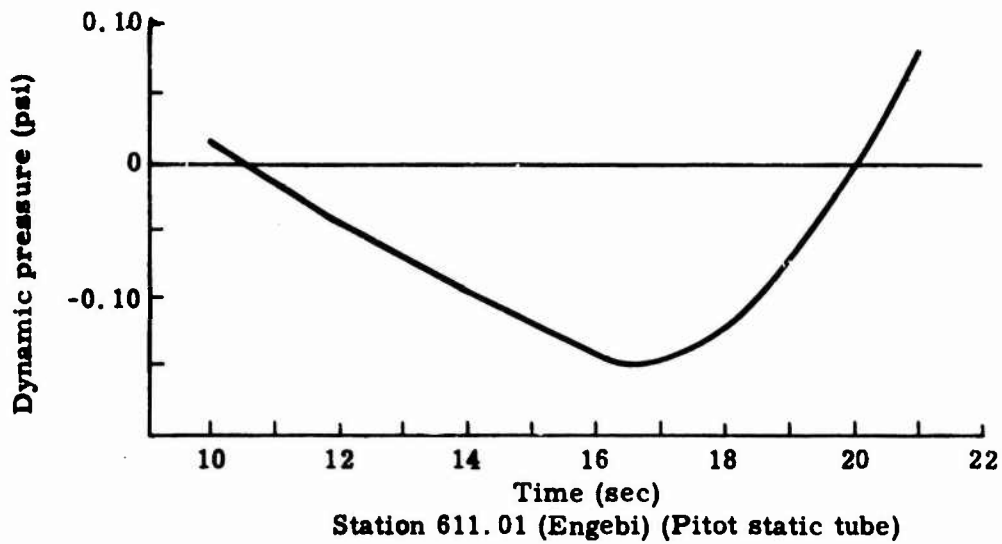
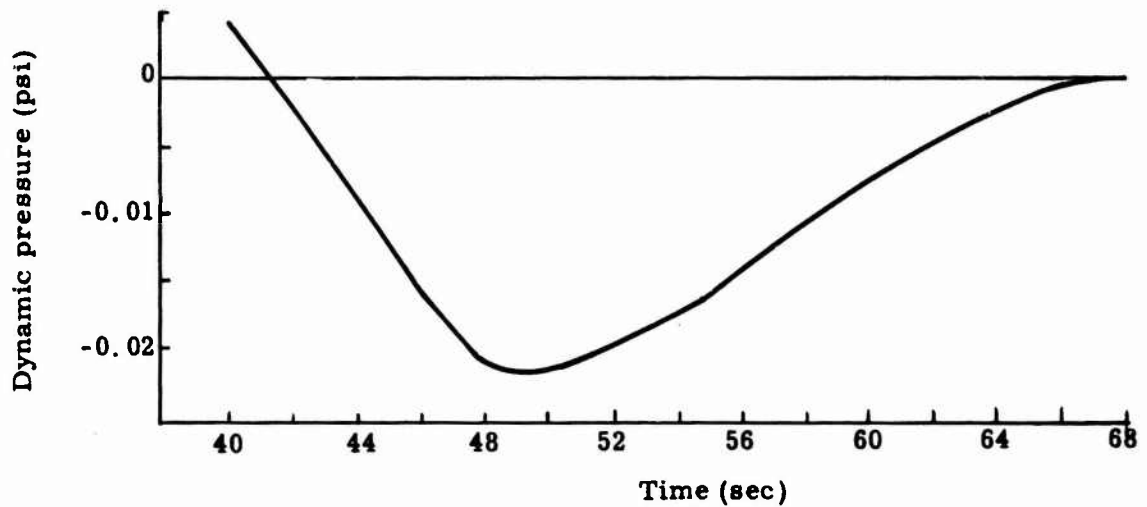
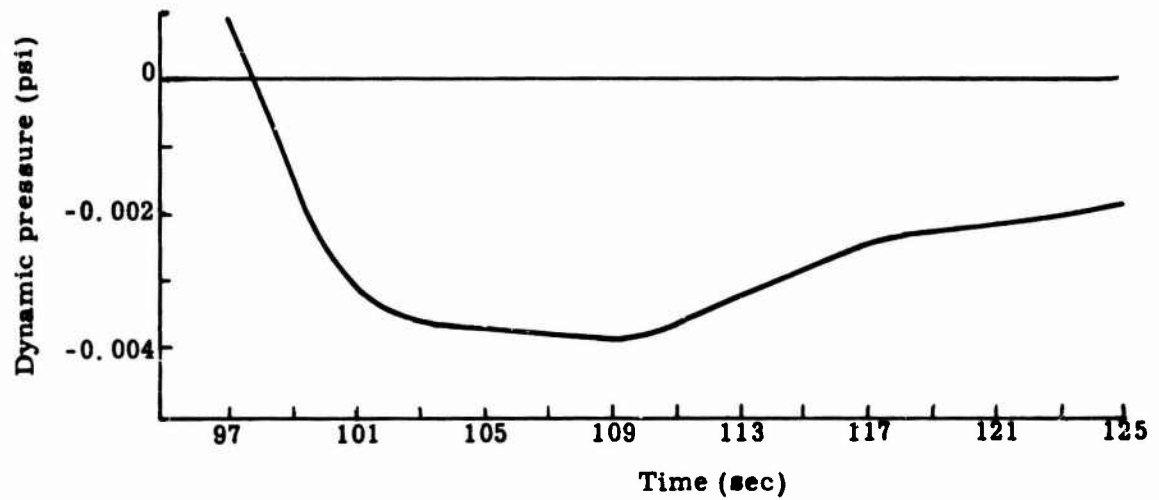


Fig. 16—Dynamic pressure-time profiles, Pitot static tube, Stations 611.01 and 611.02 (negative phase), Mike shot.

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Station 611.04 (Aomon) (Pitot static tube)



Station 612.01 (Parry) (Pitot static tube)

Fig. 17—Dynamic pressure-time profiles, Pitot static tube, Stations 611.04 and 612.01 (negative phase), Mike shot.

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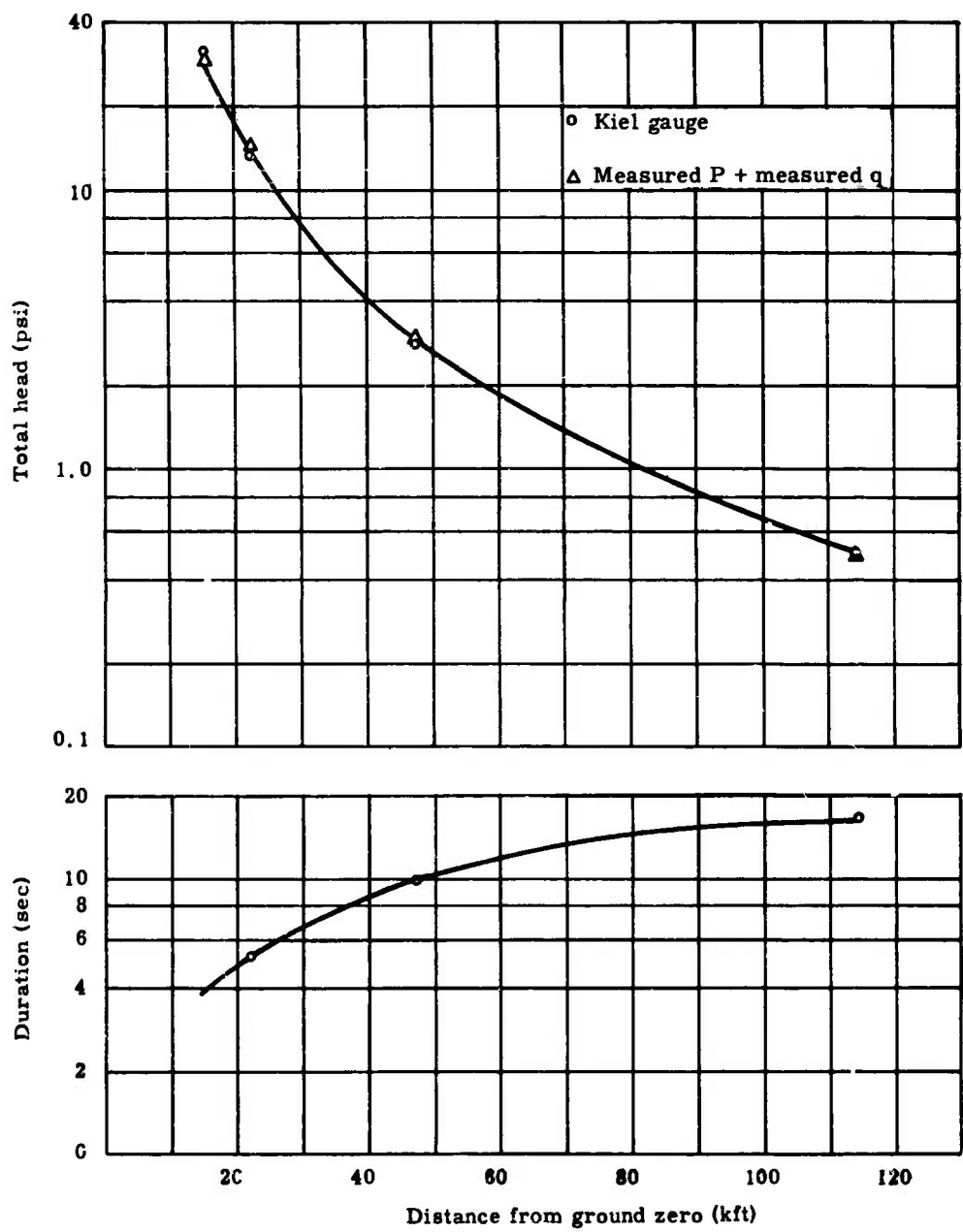
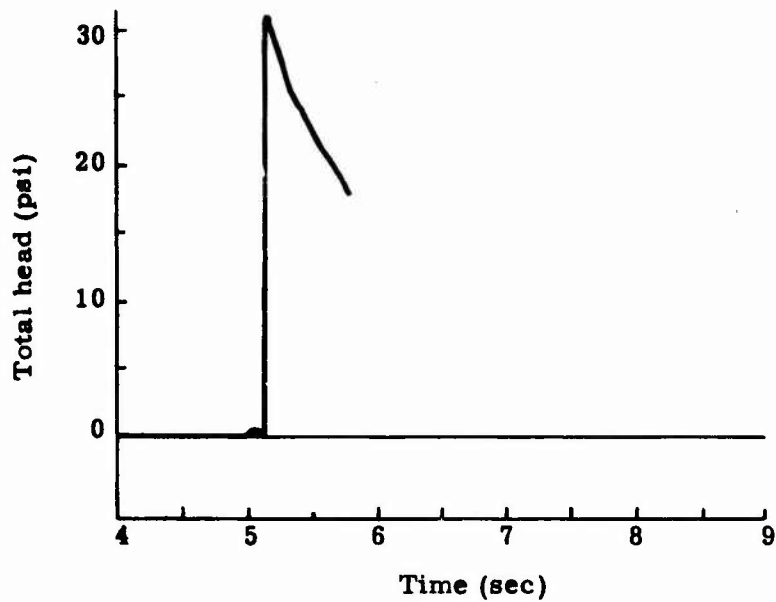
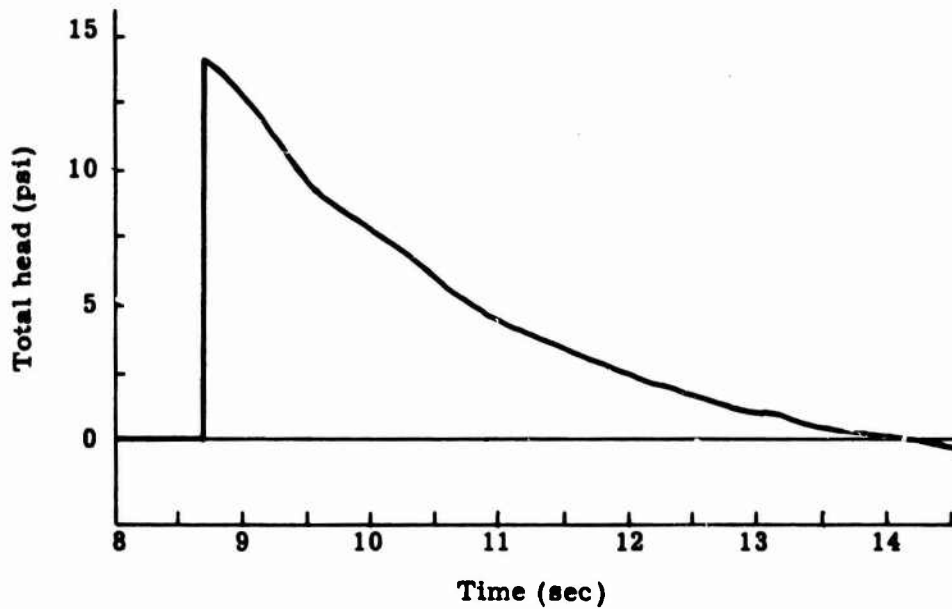


Fig. 18—Comparison of measured values for total head in the positive phase (upper curve) and positive phase durations of total head (lower curve), Mike shot.

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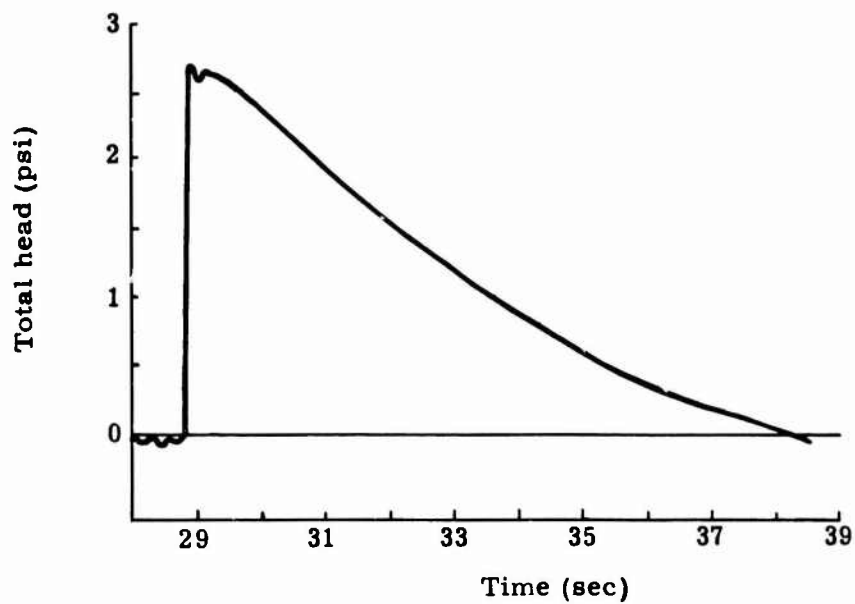
Station 611. 01 (Engebi) (Kiel gauge)



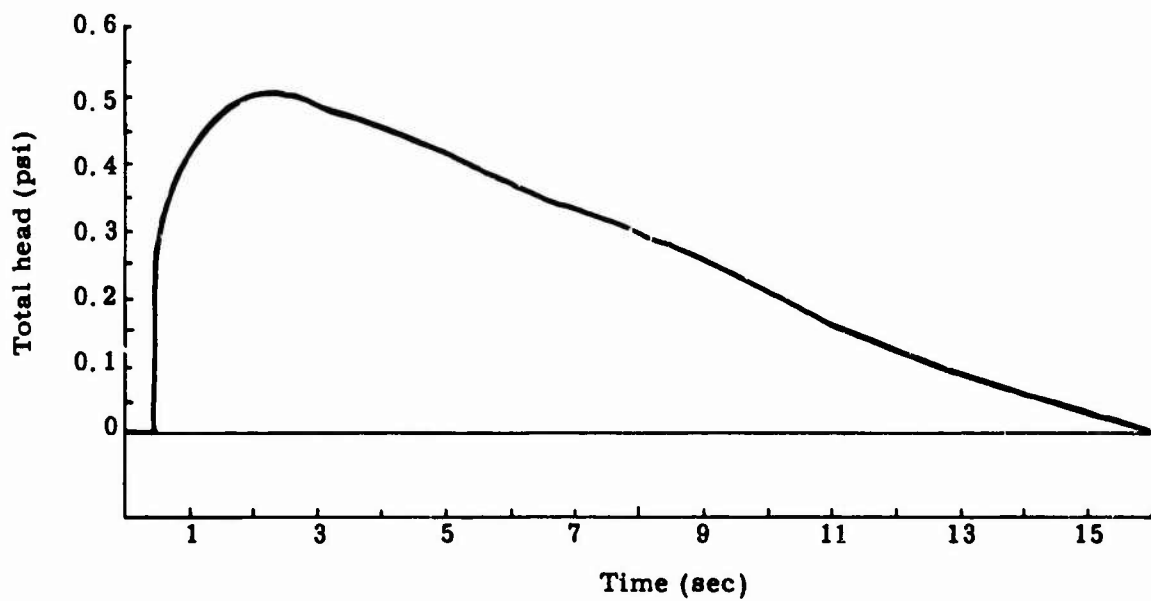
Station 611. 02 (Muzin) (Kiel gauge)

Fig. 19—Total head vs time, Stations 611.01 and 611.02 (positive phase), Mike shot.

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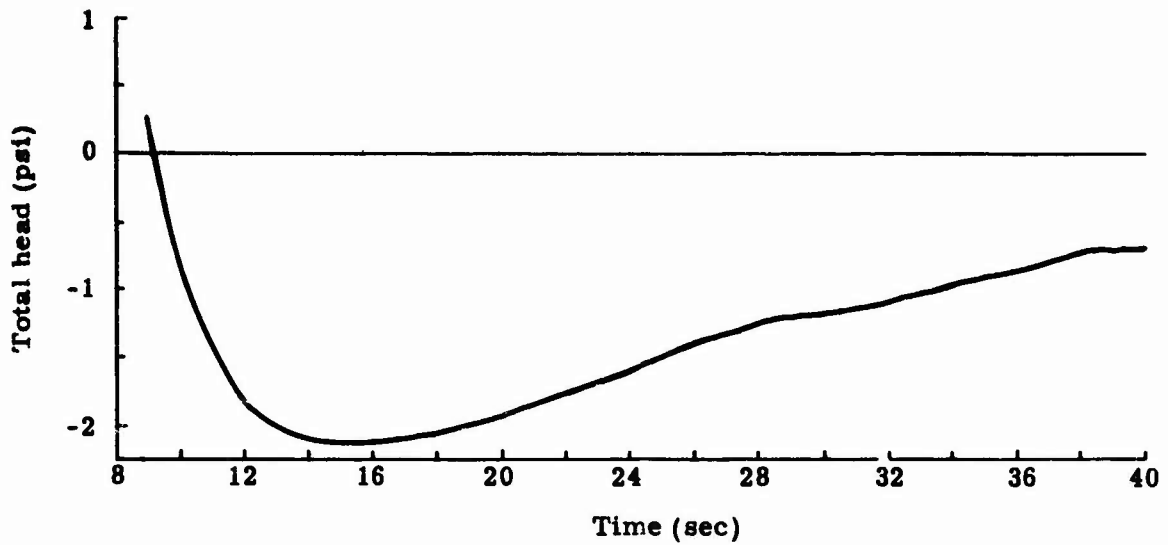
Station 611.04 (Aomon) (Kiel gauge)



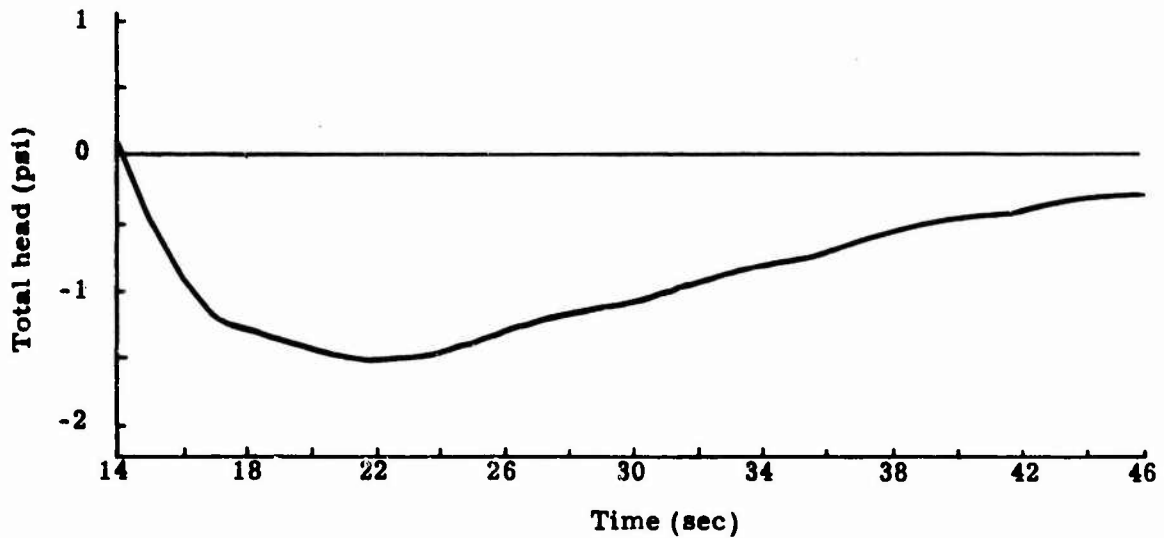
Station 612.01 (Parry) (Kiel gauge)

Fig. 20—Total head vs time, Stations 611.04 and 612.01 (positive phase), Mike shot.

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Station 611.01 (Engebi) (Kiel gauge)



Station 611.02 (Muzin) (Kiel gauge)

Fig. 21—Total head vs time, Stations 611.01 and 611.02 (negative phase), Mike shot.

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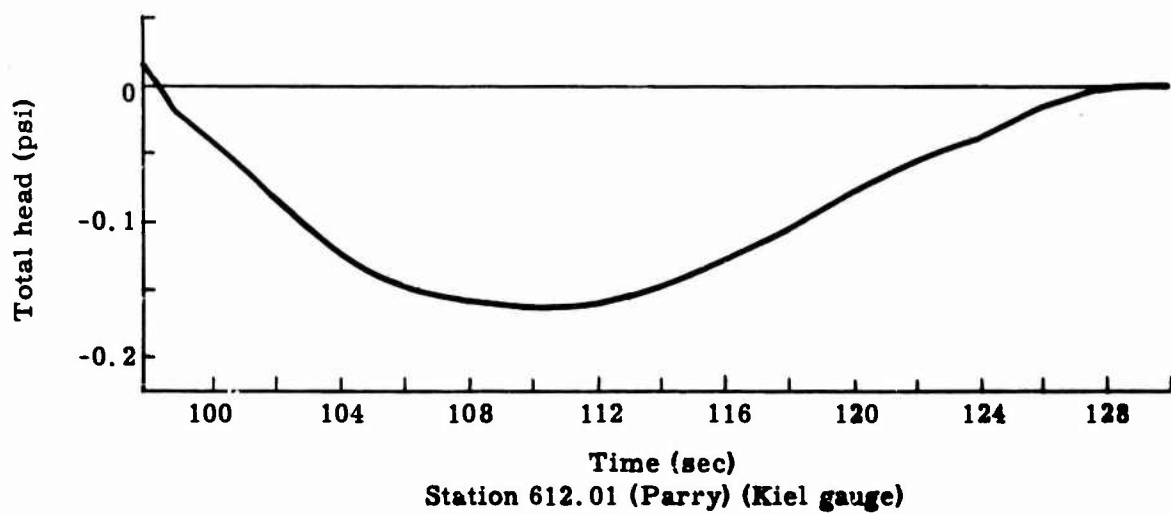
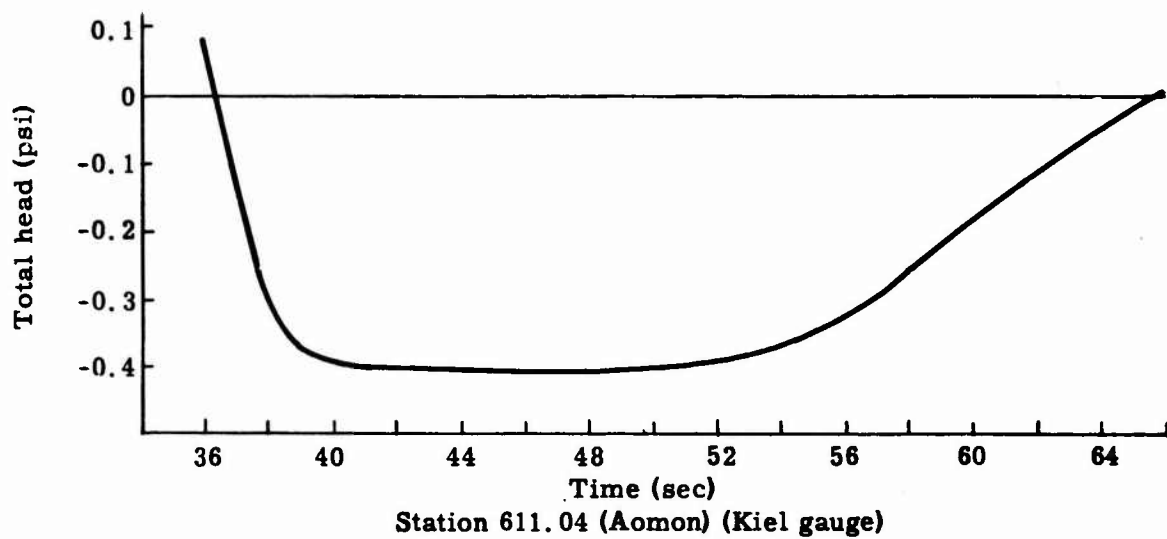
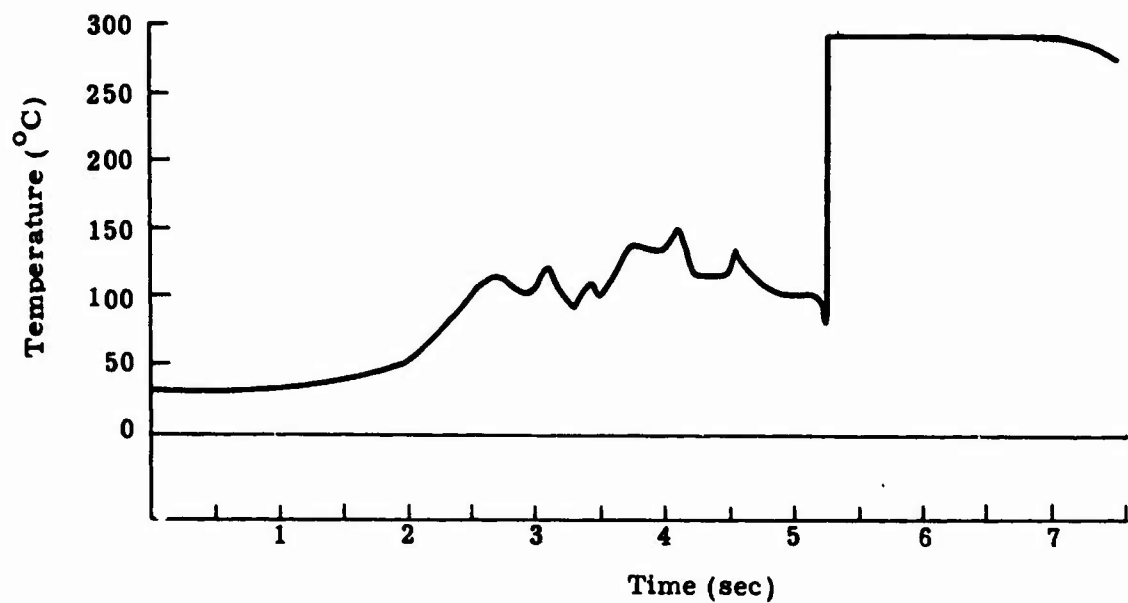
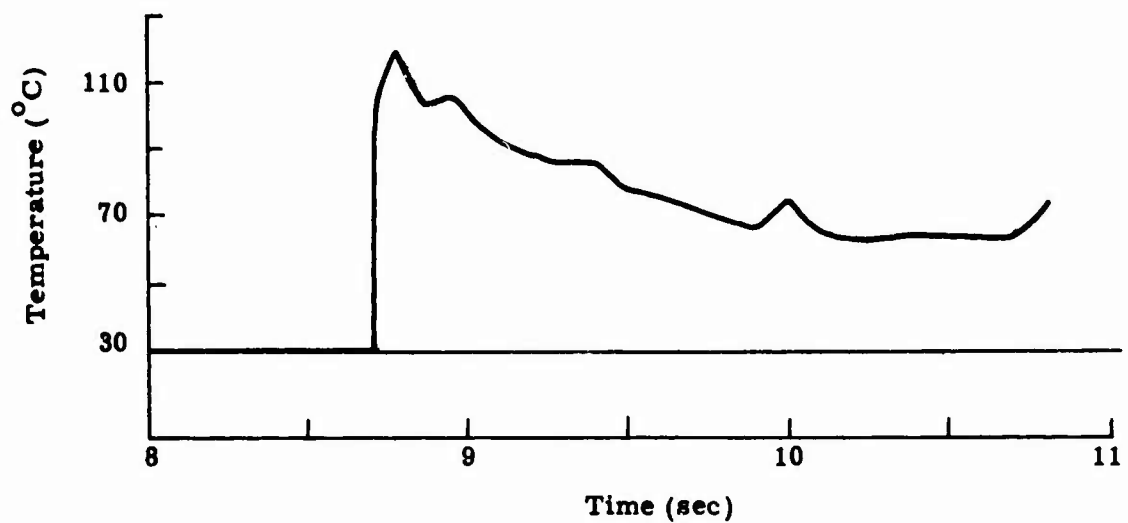


Fig. 22—Total head vs time. Stations 611.04 and 612.01 (negative phase), Mike shot.

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Station 611.01 (Engebi)



Station 611.02 (Muzin)

Fig. 23—Temperature-time profiles, Stations 611.01 and 611.02, Mike shot.

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per.⁴ It was not feasible to construct a curve for durations of the negative phase winds since only two readings were obtained.

Comparison, in Fig. 18, of the values of total head as measured by the Kiel gauge with the sums of the overpressures and dynamic pressures measured at the same locations reveals exceptionally fine agreement, an indication of the accuracy of the instrumentation. Durations of total head in the positive phase (Fig. 18) also correlate well with durations of positive phase static pressures at the same locations. Total head for the positive and negative phases at each station is plotted against time in Figs. 19 to 22.

Temperature-time profiles for the two stations at which satisfactory records were obtained are presented in Fig. 23. Only at one station, 611.01 on Engebi, was there any measured temperature rise prior to arrival of the shock front. The measured values of ΔT at these two stations agreed well with the calculated values.

5.2 King Shot

Data on King shot (Tables 7 to 9) are presented graphically in Figs. 24 to 28. Instrumentation for this shot was considerably less extensive than on Mike shot, reliance having been made on the Swassi and Pitot static tube to give the majority of the measurements desired.

A composite curve of dynamic pressure as a function of distance from ground zero was constructed from q 's based upon measured overpressures (Fig. 24), and on it were superimposed the dynamic pressures measured by the Pitot static tube and the q -gauge. Hurricane regions are again delineated on the composite curve.

Pressure-time profiles for the dynamic pressures in the positive phase are presented in Figs. 25 and 26. Because the Pitot static tube at Station 618 was blown down, the reading from it was unreliable. The gauge at Station 619.01 gave a reading 30 per cent greater than the q calculated from the overpressure. At Station 619.02 the deviation between measured and calculated q is believed to be within the range of experimental error. The fact that at Station 612.02 the measured q was much higher than the calculated q was consistent with findings on Mike shot, where the higher values of q corresponded with the occurrence of rounded wave-forms.

Pressure-time profiles for the dynamic pressures in the negative phase are presented in Fig. 27.

Durations of the positive phase winds as measured by the Pitot static tube are also plotted in Fig. 24. That at Station 619.01 seems too long in the light that at the other stations positive phase wind durations were about equal to the durations of the positive overpressures. It should be noted, however, that this station was just outside the region where the precursor had its effect on the waveform and peak overpressures, and for this reason this long duration probably should not be too hastily branded as unreal.

Total head measurements by the Kiel gauge at Station 612.02 (Fig. 28) gave clean, clear-cut records despite the fact that the signal level was apparently quite low for the set range of the gauge.

Although a peak reading only was obtained from the temperature gauge at Station 612.02, a measured ΔT across the shock front agreed reasonably well with the calculated value for this station. No temperature rise was recorded prior to shock arrival.

Examination of the Swassi records from the various stations made it evident that no information was forthcoming. Further improvements to this instrument are necessary before reliable field measurements can be made.

5.3 After-winds

An analysis of the records from the negative differential elements of the Pitot static tubes used on Mike shot revealed that in all instances in which there were no gauge or recorder failures the set range chosen was apparently too high for the gauge to distinguish the after-wind

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Table 7—DYNAMIC PRESSURE, KING SHOT

Positive Phase									
Island	Station No.	Horizontal distance from ground zero, ft	Peak overpressure, psi	Peak dynamic pressure, psi	Peak dynamic pressure,* psi	Duration of positive winds, sec	Duration of positive overpressure, sec		
Runit	618	5,491	17.6	4.6†	6.10		1.67		
	619.01	7,502	11.2	3.4†	2.61	2.91	1.68		
	619.02	10,188	8.82	1.32†	1.65	2.4	2.25		
Parry	612.01	55,132	0.42	0.015†	0.0036	4.3	4.84		
			0.42	0.01†	0.0036		4.84		

Negative Phase									
Island	Station No.	Horizontal distance from ground zero, ft	Peak negative overpressure, psi	Peak dynamic pressure, † psi	Duration of negative winds, sec	Duration of negative overpressure, sec			
Runit	619.01	7,502	1.68	0.055	17.5	8.56			
	619.02	10,188	1.32	0.052	11.0	8.93			

*Calculated from overpressure.

†Pitot static tube.

‡q-Gauge.

Table 8 — TOTAL HEAD, * KING SHOT

		Positive Phase					
Island	Station No.	Distance from ground zero, ft	Peak static overpressure, psi	Peak dynamic pressure, psi	Total head, psi	Duration of positive phase of static overpressure, sec	
						Duration of positive phase of total head, sec	
Parry	612.02	55,132	0.42	0.015	0.33	4.84	4.75

		Negative Phase					
Island	Station No.	Distance from ground zero, ft	Peak negative overpressure, psi	Peak dynamic pressure, psi	Total head, psi	Duration of negative phase of static overpressure, sec	
						Duration of negative phase of total head, sec	
Parry	612.02	55,132	0.15		0.16	10.5	11.6

*Static overpressure plus dynamic pressure as measured by the Kiel gauge.

Table 9 — AIR TEMPERATURE, KING SHOT

Island	Station No.	Distance from ground zero, ft	Peak overpressure, psi	T at zero time, °C	ΔT prior to shock arrival, °C	ΔT in positive phase of shock, °C	ΔT calculated from measured overpressure, °C
Parry	612.02	55,132	0.42	30	0	+4	2.4

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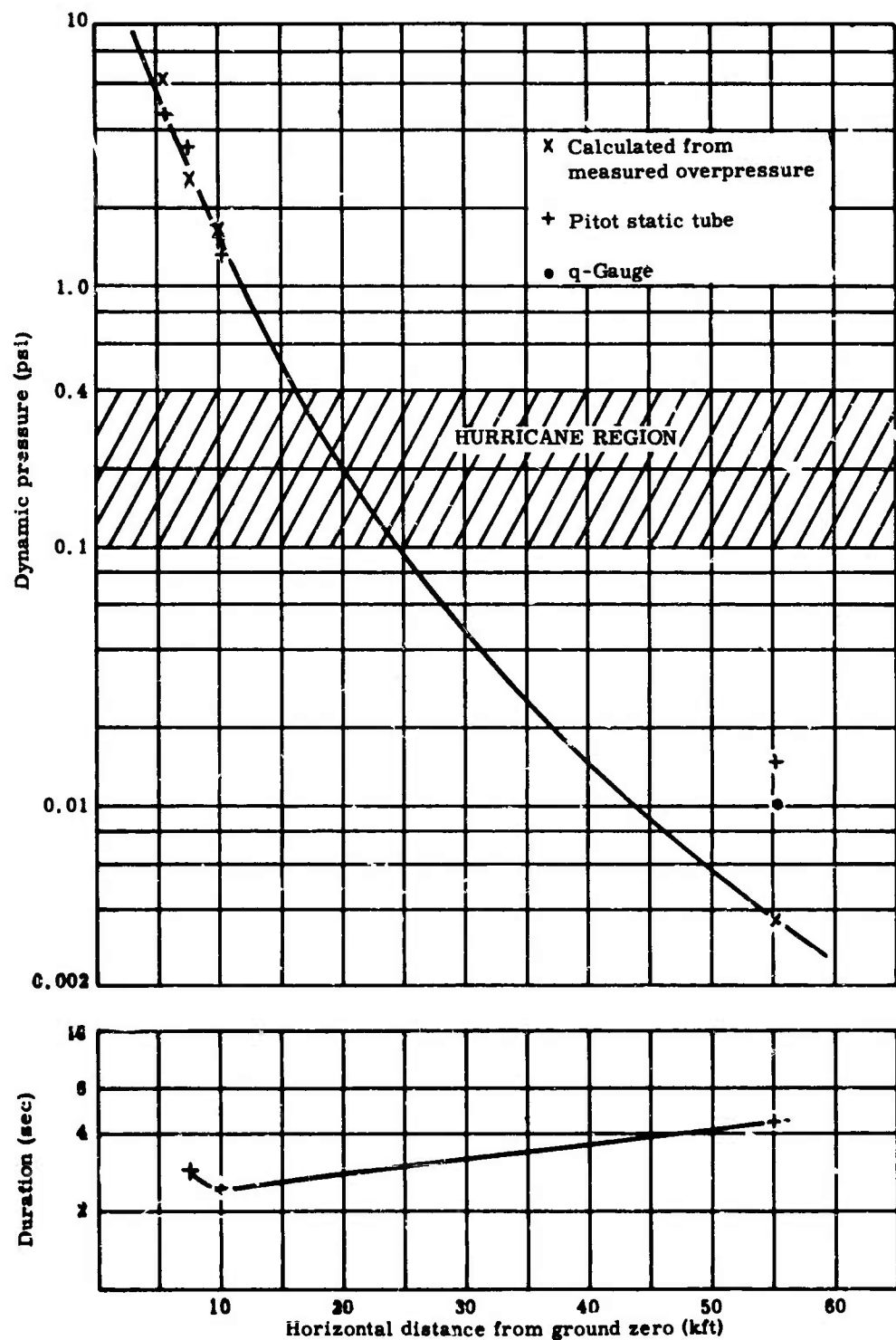
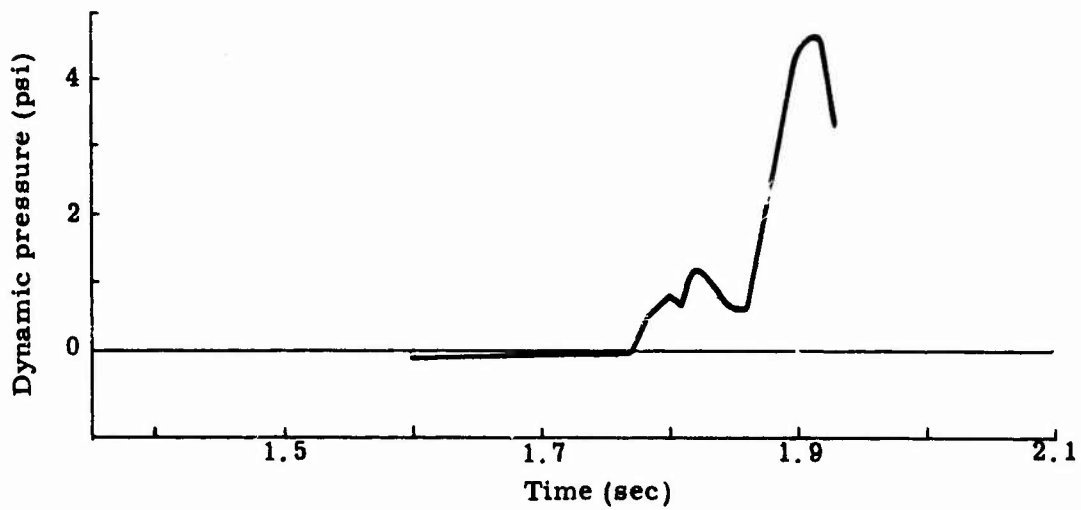
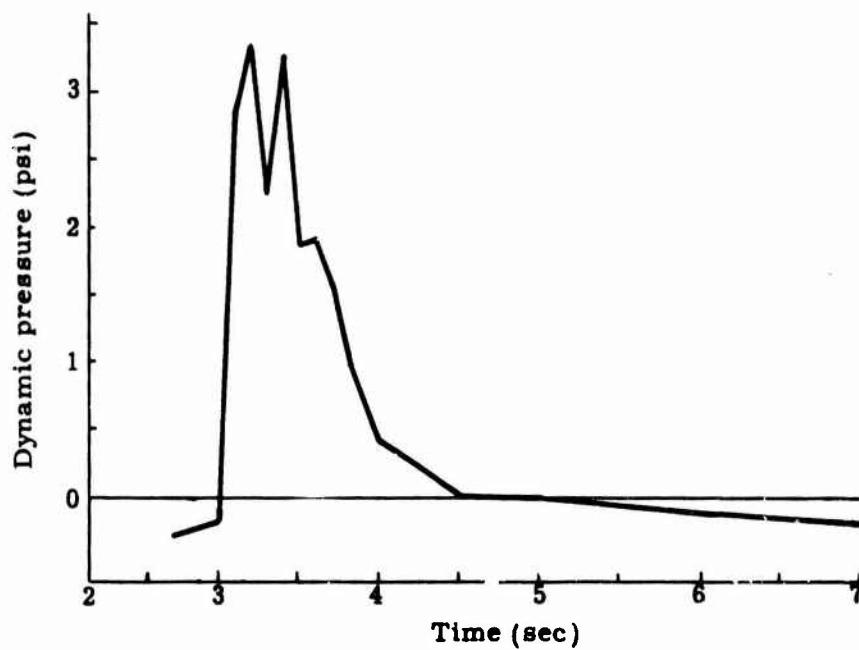


Fig. 24—Dynamic pressure and duration vs horizontal distance from ground zero (positive phase), King shot.

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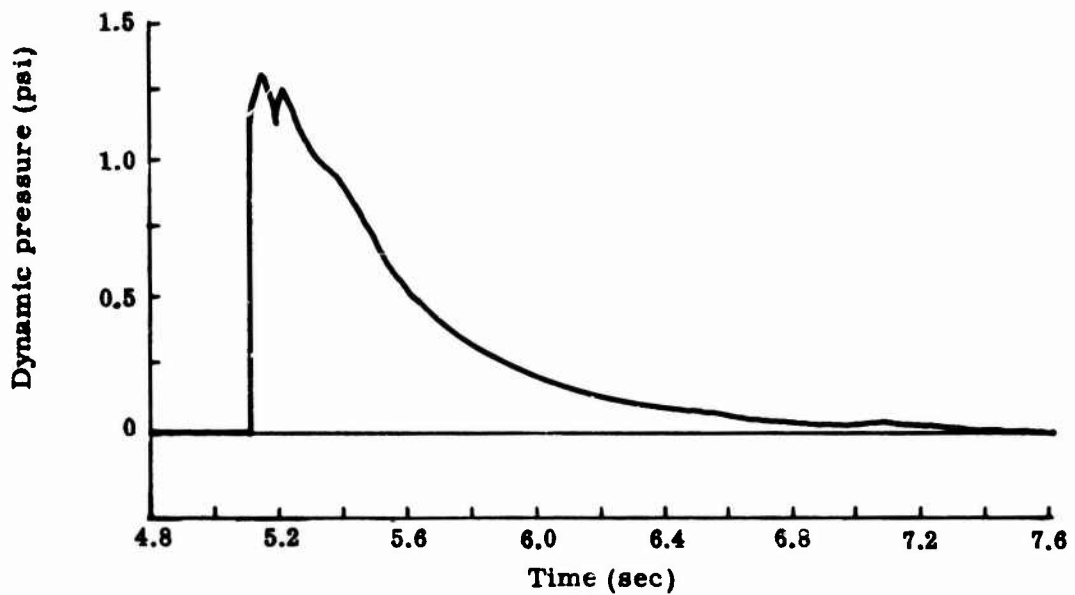
Station 618 (Runit) (Pitot static tube)



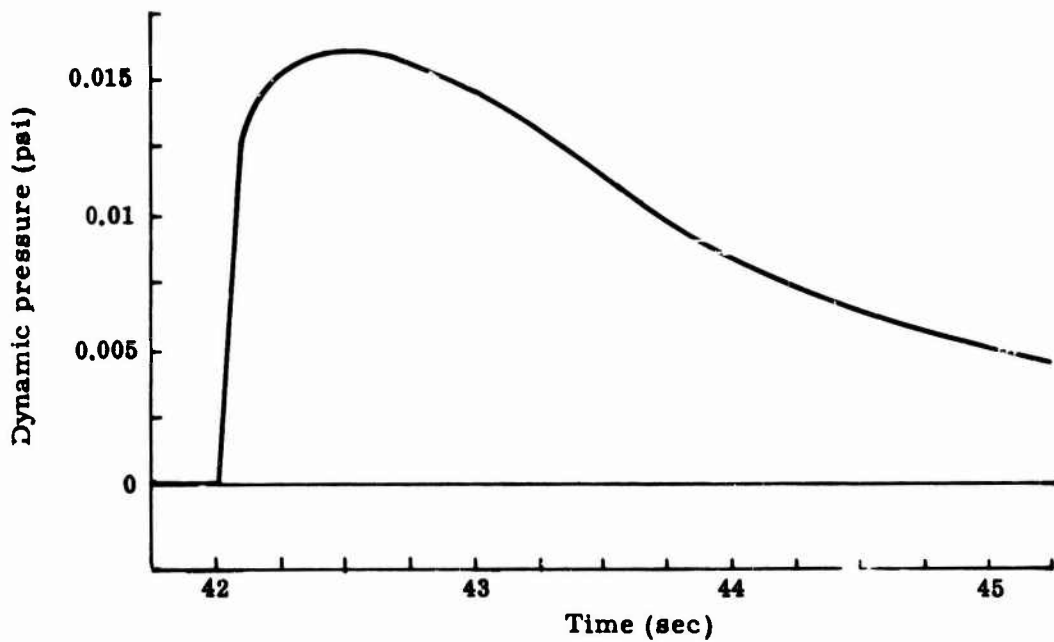
Station 519.01 (Runit) (Pitot static tube)

Fig. 25—Dynamic pressure-time profiles, Stations 618 and 619.01 (positive phase), King shot.

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Station 619.02 (Runit) (Pitot static tube)



Station 612.02 (Parry) (Pitot static tube)

Fig. 26—Dynamic pressure-time profile, Stations 619.02 and 612.02 (positive phase), King shot.

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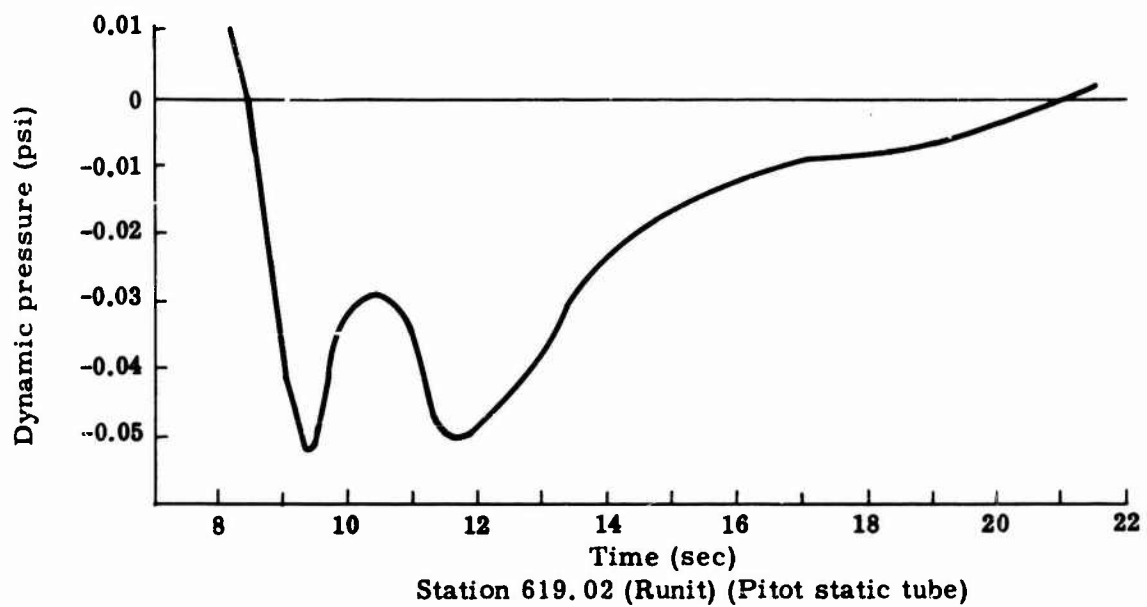
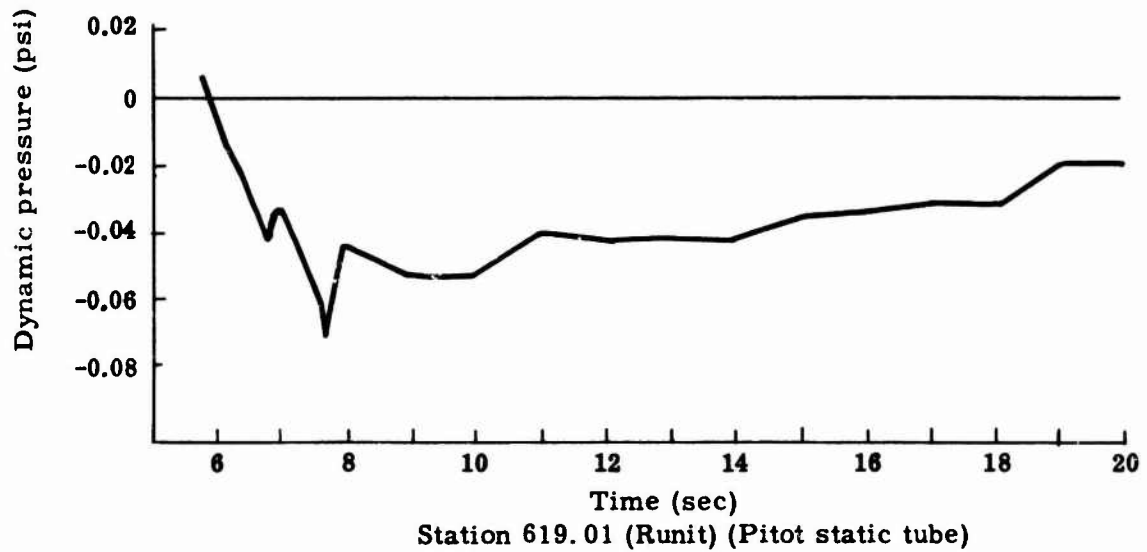


Fig. 27—Dynamic pressure-time profiles, Stations 619.01 and 619.02 (negative phase), King shot.

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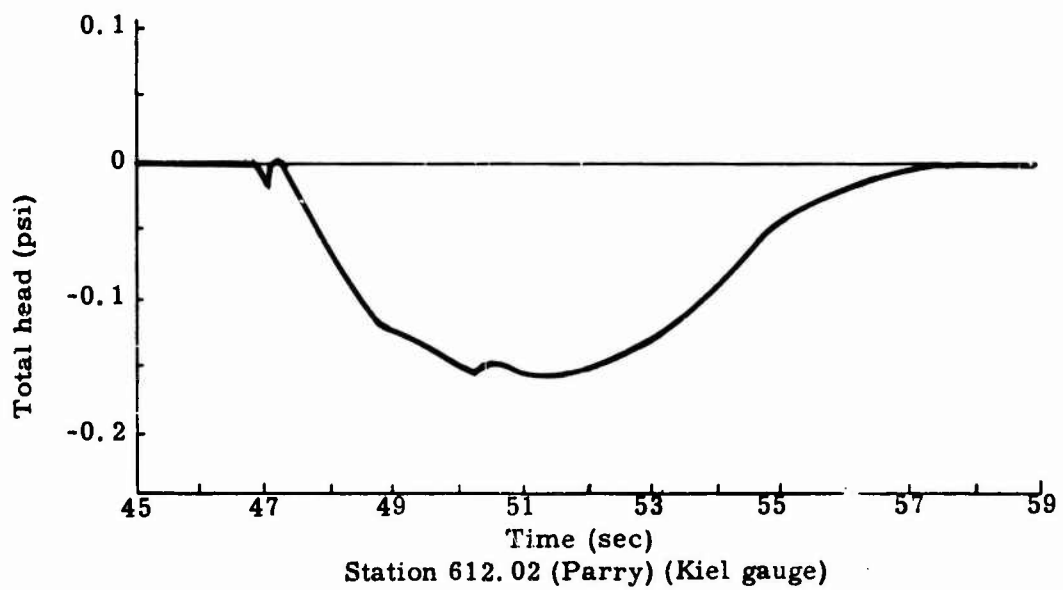
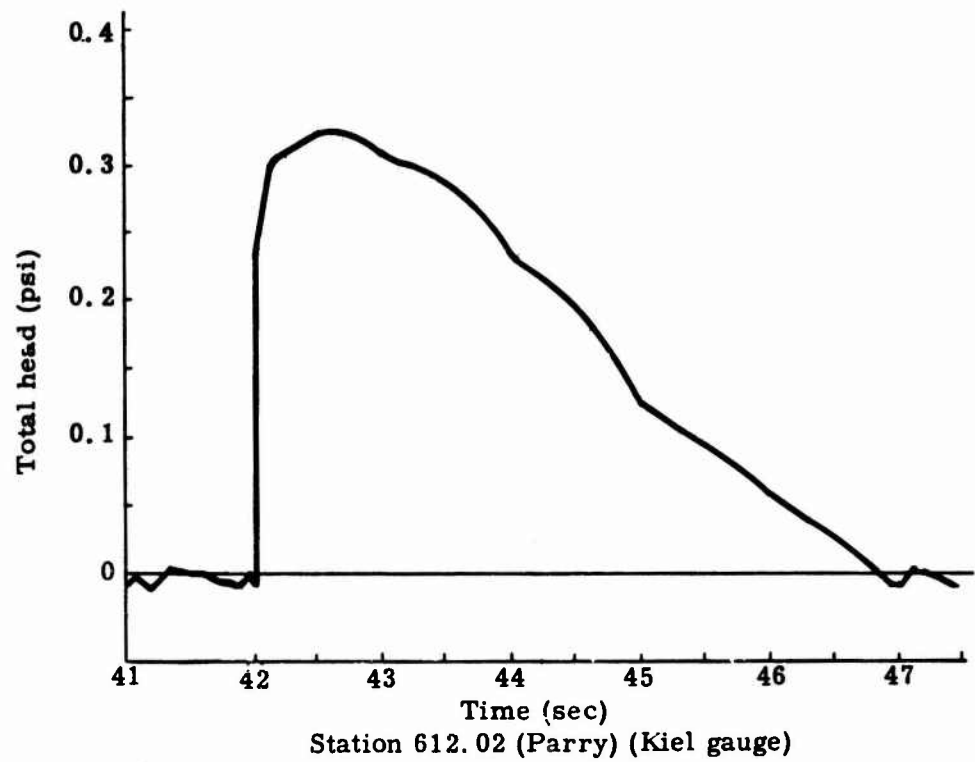


Fig. 28—Total head vs time, Station 612.02 (positive and negative phases), King snor.

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signal, if there was one, from the noise level or zero drift. The procedure followed was to attempt to establish a maximum possible value for after-winds at the station closest to ground zero, on the premise that after-winds at greater distances from ground zero would necessarily be of lesser magnitudes. No record was obtained for negative winds at Station 611.01. But the record for the negative winds from the Pitot static tube at Station 611.02 on Muzin seemed to be almost entirely free of the zero drift that characterized some of the other records. Too, the range of this gauge (0 to 5 psi) was the same as that of the gauge at Station 611.04 on Aomon, which detected negative phase winds of 0.02 psi, and that at Station 612.01 on Parry, which detected negative phase winds of 0.004 psi. Thus it seems logical to assume that the velocities of the after-winds at Station 611.02 must have been less than would be required to produce a dynamic pressure of 0.01 psi, which, at preshot air densities, would be equivalent to a wind of 24 mph. Recorders at all stations ran for approximately 9 min after zero time. Consequently it may be concluded that during the first 9 min after zero time after-winds at the last four stations on the blast line were actually of lesser velocities than the ambient winds. No appreciable after-winds were anticipated on King shot, and none were observed.

6 CONCLUSIONS AND RECOMMENDATIONS

Analysis of the data from Mike and King shots led to the following conclusions:

1. After-winds resulting from both Mike and King shots were too small to be measurable by the instrumentation used. On Mike shot they apparently had maximum velocities of less than 24 mph at 21,412 ft from ground zero.

2. Within the range of experimental error there seemed to be reasonable agreement between the measured peak changes in dynamic pressure (peak particle velocity and density) and temperature across the shock front and those calculated from the Rankine-Hugoniot equations using measured overpressures and ambient conditions.

3. Although complete histories of the blast waves on Mike and King shots were not obtained in terms of all pertinent parameters, measurements of dynamic pressure and total head in the positive and negative phases were quite successful except at overpressure levels greater than 20 psi.

4. Durations of the positive phase winds were found to be the same as those of the positive phase overpressures at most of the stations on Mike and King shots. The same sort of agreement was found between the durations of the negative phase winds and negative overpressures.

In the light of observation from this series of wind and temperature measurements it seems highly desirable in any future measurement programs of this same type to concentrate on dynamic pressure measurements at overpressure levels of 20 psi and greater and in the region of precursor formation. Further measurements of dynamic pressure at overpressure levels of less than 20 psi seem unnecessary, however, unless, of course, precursor formation is anticipated at these lower peak overpressures.

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APPENDIX A

PERSONNEL

The following personnel of the Sandia Corporation Field Test Organization, under the direction of G. A. Fowler, performed the field installation and calibration of the wind and temperature measuring instruments and auxiliary instrumentation for these measurements. H. E. Lenander of the Proving Ground Department served as Director of Project 6.1.

R. S. Millican, Division Supervisor of the Pacific Proving Ground Division
J. H. Scott, Project Engineer

Bell, H. E.	Looney, T. C.	Spilker, R. E.
Beyeler, J. A.	Mesnard, J. M.	Swartzbaugh, H. S.
Bolinger, N. C.	Minck, J. L.	Thompson, R. H.
Bunker, R. B.	Morrison, J. H.	Thornbrough, A. D.
Covington, M. B., Jr.	Neil, S. D.	Valentine, J. W.
Csinnjinni, C.	Pritchett, R. E.	Wistor, J. W.
Gross, W.	Reis, G. E.	Witt, L. J.
Hampson, E. P.	Richardson, H. M.	Wood, E. E.
Landes, G. N.	Shannon, E. V.	Yearout, R. M.
List, D. B.	Smith, J. W., II	

The following military personnel were assigned temporarily to the Field Test Organization for assistance on Operation Ivy:

Bonham, W. D.	Korbe, A. J.
Daniel, V. H., Jr.	Mandrell, W. L.
Gobble, D. E.	Meinert, R. E.
Green, J. R.	Payne, W. G.
Greenleaf, D. E.	Vaughn, J. F.
Kelso, C. J.	

E. F. Cox, M. Cowan, Jr., and G. W. Kollooson of the Weapons Effects Department participated in the field operations.

The following personnel from the Weapons Effects Department of Sandia Corporation, under the direction of E. F. Cox, who also served as Codirector, with F. B. Porzel, Los Alamos Scientific Laboratory, of Scientific Program 6 of Operation Ivy, assisted in the analysis of the data obtained on these measurements:

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Cook, T. B., Jr.
Cowan, M., Jr.
Murphey, B. F.

Rollosson, G. W.
Shelton, F. H.
Shreve, J. D., Jr.

All data were reduced by the Mathematical Services Division, 5242, of Sandia Corporation.



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MEMORANDUM FOR DISTRIBUTION

SUBJECT: Declassification Review of Operation IVY Test
Reports

The following 31 (WT) reports concerning the atmospheric nuclear tests conducted during Operation IVY in 1952 have been declassified and cleared for open publication/public release:

WT-602 through WT-607, WT-609 thru WT-618, WT-627 thru WT-631, WT-633, WT-635, WT-636, WT-639, WT-641 thru WT-644, WT-646, and WT-649.

An additional 2 WTs from IVY have been re-issued with deletions. They are:

WT-608, WT-647.

These reissued documents are identified with an "Ex" after the WT number. They are unclassified and approved for open publication.

This memorandum supersedes the Defense Nuclear Agency, ISTS memorandum same subject dated August 17, 1995 and may be cited as the authority to declassify copies of any of the reports listed in the first paragraph above.


RITA M. METRO
Chief, Information Security